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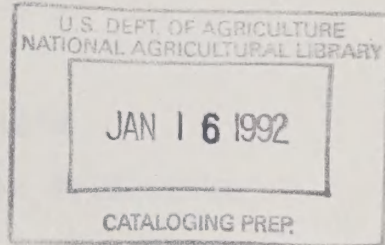
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REGIONAL PROJECT OUTLINE



ENGINEERING SYSTEMS

FOR COTTON PRODUCTION

February, 1973

Effective date: July 1, 1973

Cooperators: The Agricultural Experiment Stations of Alabama, Arizona, Arkansas, Georgia, Louisiana, Mississippi, New Mexico, North Carolina, Oklahoma, South Carolina, Tennessee, and Texas, and the USDA Agricultural Research Service.

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REGIONAL PROJECT OUTLINE

- (1) Project Number -- S-69
- (2) Duration -- July 1, 1973 to June 30, 1978
- (3) Title -- Engineering Systems for Cotton Production
- (4) Objectives --
 - A. Document and demonstrate the computer simulation of cotton production and processing models developed to date under the S-69 project.
 - B. Develop and improve subsystem models for use in up-dating the overall production and processing simulation.
 - C. Evaluate new and alternative production and processing practices through the application of simulation models and other experimental techniques.
- (5) Procedure --
 - A. The several simulation models developed under the S-69 project to date will be documented and interfaced with each other to provide an over-all simulation of cotton production and processing. Their use will be demonstrated to cooperators by developing a users' manual and by conducting training sessions. Documentation will be accomplished by obtaining verification data at selected locations within the region and through publication. Participants will utilize the models to

test their validity at each location or send the verification data to the coordinator's office to be verified by the model developers. The following responsibilities are assumed:

1. Documentation and verification of models.
 - a. Plant Model - ARS at Mississippi State, Stoneville, and Lubbock, and Arkansas, Louisiana, South Carolina and Tennessee
 - b. Harvest, Transport, Gin Model - Arizona
 - c. Machinery selection - Arizona
 - d. Storage and handling - ARS in Mississippi, Texas and Arkansas
 - e. Emergence model - ARS in Texas, Arkansas and North Carolina
2. Interfacing of existing and new models into an overall model - North Carolina and ARS in Mississippi
3. The users' manual will be developed under the direction of the coordinator's office by: ARS in Mississippi and Texas, and North Carolina
4. Seminars for guidance in the application of models to research problems will be scheduled by the Executive Committee and conducted by the model developers.

B. Work on development and improvement of subsystem models for completing and up-dating the overall production model will be done as follows:

1. Machine-soil model - North Carolina and Louisiana will develop a model to describe the machine-soil relationship for various machines and soil properties. Alabama will cooperate in regard to soil compaction.
2. Emergence model - ARS at Lubbock will improve the emergence model as suggested by users in other areas.
3. Plant Model - Improvement and updating of the plant model will be done by ARS at Mississippi State.
4. Insects - ARS in Mississippi and California will develop models to simulate populations and distributions of important cotton insects as affected by food availability, egg laying sites, environment surrounding vegetation, and predators' interactions with the cotton production model.
5. Weeds - South Carolina will develop a computer model for the germination and growth of five major weed species in competition with cotton and with competition among the weed species. Different levels of weed control will be simulated utilizing the model to evaluate alternative production practices. No weed control will be included as an alternative. The model will be verified by field experimentation.

6. Harvest-Transport-Gin - ARS in Mississippi and Texas will continue to develop and improve models to evaluate harvesting-handling-ginning systems, including trailer and turnrow storage models.
 7. Soil-Plant Model - North Carolina and Alabama will cooperate and Oklahoma and New Mexico will collaborate in the development of root models as they relate to soil type, moisture regimes, tillage parameters, and plant, water and nutrient stress.
 8. Nematode and Disease Models - North Carolina will assume responsibility for liaison between Pathology and Nematology to promote the development of nematode and disease models and interface them with the S-69 model.
- C. New and alternative production practices will be developed and/or evaluated through the application of models as follows:
1. Plant Model
 - a. ARS at Lubbock will simulate the effects of changing selected production practices on vegetative and fruiting development of the cotton plant. Variables will include spatial plant distribution vs. weather regimes and defoliation scheduling.

- b. Alabama will use this model to determine the effects of plant populations and planting configurations on vegetative growth and on yields. Variables will include plant spacing in the drill and row spacing. Simulation models will be used to determine the plant population and plant configuration to be field tested for a stripper-harvested, close row production system.
- c. Arkansas will use this model to evaluate narrow row, restricted traffic, cultural systems.
- d. ARS and Mississippi at Stoneville will use this simulation to evaluate row patterns and inter-row plant spacings for developing a production system on wide (2.5 meters) beds.
- e. North Carolina will use the plant model to establish the minimum soil volume required by the plant root system to maintain the desired boll load during stress periods, nitrogen level, etc.
- f. South Carolina will use the plant model and field experimentation to investigate the effects on cotton production and harvesting of three different systems of twin-row planting compared with conventional row spacing.

2. Emergence model

- a. Alabama and North Carolina will use historical weather data to establish the frequency and intensity of stress periods during the planting season and relate these to cultural practices, planting practices, and timing through the use of these moisture-temperature and emergence models.
- b. Arkansas will use the plant emergence model to evaluate the effects of seed zone temperatures and physical impedance modifications on emergence on three typical Mississippi Valley soils.
- c. Oklahoma will utilize this model to evaluate the effects of such input parameters as soil moisture, soil temperature, and germination and will use these results in planning research designed to improve emergence.

3. Machine-soil Model

- a. ARS at Stoneville will use this model to determine effects from traffic on wide (2.5 meter) bed cultural systems on soil compaction and availability of nutrients for plant growth.

- b. Arkansas will also use this model, along with the plant model, to evaluate narrow-row, restricted traffic cultural systems.
- c. Oklahoma will use this model in connection with seedbed preparation-planter research. Field data will be used as input to the model to determine areas of needed research. Indicated research will then be initiated.

4. Insect models

- a. Alabama will use insect models to develop insecticide application schedules and integrate with a biological-chemical control program.
- b. Tennessee will use insect models to investigate economic thresholds of major cotton pests in an area of low boll weevil pressures.

5. Weeds model

- a. Arkansas will use the weed control model to evaluate alternate control systems for effectiveness and costs on three typical Mississippi valley soils.
- b. Tennessee will use the weed model to investigate the effects of densities of major weeds on moisture content of seed cotton, yield and grade.

6. Harvesting, Transportation, Gin

- a. ARS at Mississippi State and Texas A & M will use this model to evaluate the seedcotton module builder and ricking system and apply the model to evaluate against alternative systems of seedcotton handling.
- b. Arkansas will evaluate alternate systems of seed cotton storage and handling and will attempt to apply the model to evaluate and improve their unique system.
- c. Oklahoma will study the simulated effects of arbitrarily altering the levels of some of the input variables to search for the most nearly optimum or profitable combinations of variable levels. Identification will be made of the variables which might feasibly be altered to produce profitable results. Experiments will be designed to evaluate the indicated alterations.

7. Machinery Selection - Alabama and Arizona will use this model to develop optimum selection and utilization techniques for farmers.

(6) Justification: Cotton will continue to play a vital role in the agricultural economy of the region if it can compete

effectively with synthetic and foreign production. Additional engineering research is needed to reduce the cost of production. The S-69 project has been designed to use the computer simulation techniques to facilitate research in engineering aspects of production toward the goal of cost reduction.

The simulation of a production system has three major purposes each of which may justify the activity: (a) to guide the research for improving the efficiency of the production system; (b) to reduce the cost of applied research by testing the interactions of weather and cultural practices on the computer; (c) to optimize management systems once all of the major crop production systems have been simulated with verified mathematical models. This revision of S-69 is primarily concerned with purposes (a) and (b).

The S-69 cotton production simulation model is a result of multi-disciplinary effort and the development and verification of such models fosters inter-disciplinary research.

The development and use of a simulation model is one of the most effective techniques available for focussing attention on areas needing further research and for setting priorities on research activity. Various aspects of the cotton production system have been studied extensively, but

the overall production system has not been optimized. Further research without integrating all important subsystems into a simulation model of the cotton production system would be unlikely to result in an optimum system. Attempts to verify the simulation model by comparing with field results will point out where further work is needed.

A substantial part of the research on the cotton production system will transfer effectively to other crop systems. The techniques of CH_2O balance, Nitrogen balance, and water balance will apply to other crop systems in one form or another. The techniques used in developing the emergence model could be duplicated for soybeans or peanuts. The entire soil-cultural practice subsystem will transfer intact without modification for soybeans, peanuts, corn, tobacco and small grains. Thus, the investment in the cotton production system simulation is an investment in the simulations of all other crops. Although considerable progress has been made on the original objectives of S-69, additional effort will be necessary to complete the project.

- (7) Related Current Research - Review of a CRIS printout on mechanization of cotton production shows that states presently engaged in this research are now members of S-69.

An exception is New Mexico. ARS research at Shafter, California is coordinated through other ARS membership in S-69. As far as we know, all of the simulation modeling work concerning engineering systems in cotton production is being done in this project. There are however, a number of scientists working in modeling of other crops and pests. Entomologists in Arkansas, California, Mississippi, Texas and the USDA Agricultural Research Service are working on insect models under the IBP-Biological Control Project; and in several cases the cooperating engineers are connected with the S-69 Project. This work is just getting underway, and as far as we know, there have been no publications yet. Fye and Butler in Arizona have a cotton insect model working (6-9, 16-19). Brewer (ARS has several insect models under development in California (3-5). Menke in Florida has a model of a leaf eater on soybeans. Ritchie (ARS) has a soil-water model running at Temple, Texas (27). Hearn at the Kimberly Research Station in West Australia is developing a dynamic model of cotton morphogenesis (24,25). Lambert at Clemson University is engaged in an effort to simulate weed growth and competition in cotton, and is a participant in the S-69 project. Curry in Ohio is developing a dynamic model of plant growth in corn and soybeans (10,11). Duncan has been working at the University of Kentucky and the University

of Florida for many years on a model of corn growth and reproductive physiology; and the basic model of Simcot is based on his work (14,15). Goldstein at Oakridge National Laboratory is working on the IBP project dealing with the Eastern Deciduous Forest Biome, including the soil hydrology-plant-root interface model, SOGGY (20-23). Barrett, Purdue University, is working with a corn borer population-life cycle model (1,2). At the Agricultural University, Wageningen, Netherlands, members of the Department of Theoretical Production Ecology are modeling important subsystems of the crop production systems, including plant growth and physiology, soil-root and air-plant interfaces, plant competition and insects. (28,29,32, 36-38) Huck is working with the USDA, ARS Soil-Water Institute at Auburn on cotton root systems.(26). At Cornell, Lemon and others are working on SPASM, a soil-plant-atmosphere simulation model (30,34).

- (8) Previous Work and Present Outlook -- Work on engineering systems for cotton production, using simulation modeling techniques was begun under this project in 1969. The objectives of this project have been partially met. A first order model of the general cotton production system has been developed that includes a seedling emergence model(5,9) a plant (1), and a harvest-handling

ginning model (4). Continuing work will be needed to simplify these models for application. Other subsystem models under various stages of development include a machine-soil model (6), an insect model (2), and a weed model. All of these models will require further development, verification data and testing. Following this, these models will need to be interfaced into the overall production model.

- (9) Organization -- A Regional Technical Committee shall outline the area of work, assign responsibility, review progress, issue reports and publications, and perform other administrative tasks associated with the regional project. This committee shall consist of one technical representative from each cooperating state and one member from the cooperating USDA agency. A chairman shall be elected each year from the state members.

An Executive Committee composed of three; namely, one state Technical Committee member from each of the three areas, Southeast, Mid-South and Southwest shall serve in the interim between meetings of the Technical Committee and to perform other duties as delegated or assigned by the Technical Committee. They shall be elected by the Technical Committee. The Director's Representative, a Technical Committee member from the

Agricultural Research Service of USDA, a representative from CSRS, and the Coordinator may meet with the Executive Committee as non-voting members. The Chairman of the Technical Committee shall serve as Chairman of the Executive Committee.

An Agricultural Engineer, with the title of Coordinator, shall assist in certain phases of the research and in performing the coordinating functions of the Technical Committee. He shall maintain liaison and promote cooperative effort among the several states and USDA agencies through correspondence, personal visits and the transmission of pertinent information. He shall also participate in the assembly of data, the preparation of annual reports, and the preparation of manuscripts for publication. The Coordinator shall serve as secretary to both the Technical and Executive Committees. His salary and expense shall be met jointly by the Agricultural Research Service, USDA, and the Mississippi Agricultural Experiment Station.

(10) Signatures:

Recommended for approval:

Southern Director's Representative

Date

Chairman, Southern Director's Assn.

Date

Chairman, Committee of Nine

Date

Approved:

Administrator, CSRS

Date

(11) Attachments:

Project Leaders --

Alabama: W. T. Dumas, Agricultural Engineer, Auburn
Arizona: W. W. Hinz, Agricultural Engineer, Tucson
Arkansas: E. J. Matthews, Agricultural Engineer, Fayetteville
Louisiana: R. W. Whitney, Agricultural Engineer, Baton Rouge
Mississippi: E. B. Williamson, Agricultural Engineer,
ARS & DBES, Stoneville
New Mexico: G. H. Abernathy, Agricultural Engineer, Las Cruces
North Carolina: H. D. Bowen, Agricultural Engineer, Raleigh
Oklahoma: D. G. Batchelder, Agricultural Engineer, Stillwater
South Carolina: T. H. Garner, Agricultural Engineer, Clemson
Tennessee: J. A. Mullins, Agricultural Engineer, Jackson
Texas: L. H. Wilkes, Agricultural Engineer, College Station
E. B. Hudspeth, Agricultural Engineer, ARS, Lubbock
ARS: R. F. Colwick (Coordinator), Agricultural Engineer,
Mississippi State, Mississippi.
H. L. Brewer, Agricultural Engineer, Shafter, California
W. M. Carleton, National Program Staff, Washington, D.C.
L. A. Smith, Agricultural Engineer, Auburn, Ala.

Anticipated Resources:

<u>Cooperating Agency, Location</u>	<u>Est. SMY/Yr.</u>
Alabama AES, Auburn	.30
Arizona AES, Tucson	
Arkansas AES, Fayetteville	.60
Louisiana AES, Baton Rouge	.50
Mississippi AFES, Mississippi State	.10
North Carolina AES, Raleigh	.25
Oklahoma AES, Stillwater	1.25
South Carolina AES, Clemson	.20
Tennessee AES, Jackson	.20
Texas AES, College Station	.30
ARS: Mississippi State, Miss	2.00
Stoneville, Miss	.20
Lubbock, Texas	1.00
Auburn, Alabama	<u>.30</u>
TOTAL	7.20

Critical Review

The objectives of the original S-69 project have been partially met. Under objective A, several cotton production subsystem models have been developed and are in the process of being interfaced with each other to provide a generalized cotton production system. A cotton emergence model has two seasons of verification data from six locations across the cotton belt. The plant model has one year of general verification data from five locations across the region. Harvest-handling-ginning models have been developed by cooperating personnel in Arizona, Mississippi and Texas, and one year of data has been taken in the High Plains area of Texas and Arizona. The latter two need further verification and testing. More detailed descriptions of several of these models are appended.

Other models under development are machine-soils, insects, weeds, defoliation and machinery selection. These models need further development before they are ready for verification and interfacing.

Under objective B, research has developed improved production techniques and provided verification data for the several models being developed under objective A.

Under objective C, those researchers participating in model development have been using simulation techniques to evaluate cotton production subsystems. This activity will be strengthened under this revision by providing for the development of model users' manuals and training techniques.

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Appendix to Critical Review

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SUMMARY
OF
SIMULATION MODELS
1972

REGIONAL PROJECT S-69
ENGINEERING SYSTEMS FOR COTTON PRODUCTION

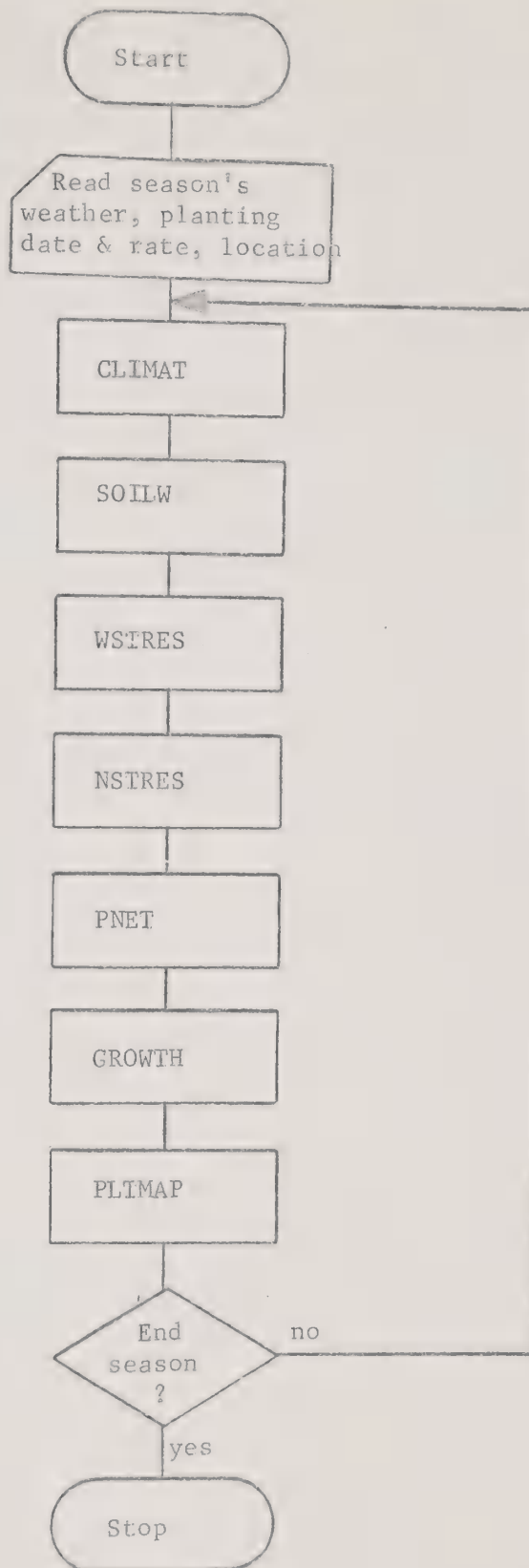
S I M C O T III

A model simulating growth and yield in cotton

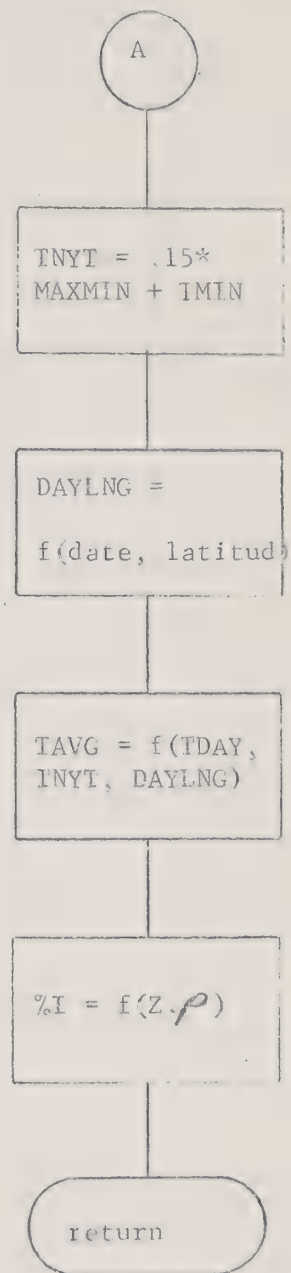
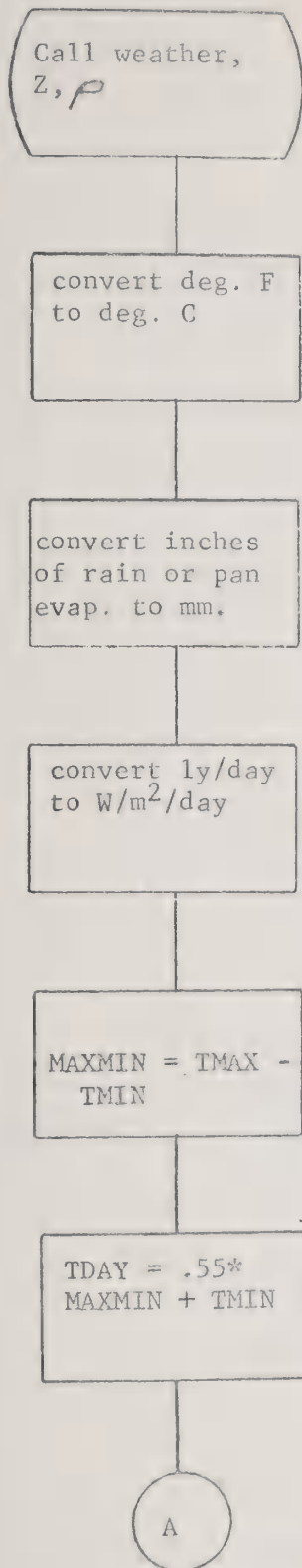
Donald N. Baker (Soil Scientist) and James M. McKinion (Electrical Engineer)
The Cotton Production Research Institute (Biological Systems), ARS - USDA
P. O. Box 5367
State College, Mississippi
39762

and weight increases. The basic concepts of growth from the photosynthetic production of carbohydrate and the abscission of fruit in response to carbohydrate stress remain. The notion of leaf senescence and abscission, and its effect on light interception and the resulting feedback on photosynthesis are incorporated.

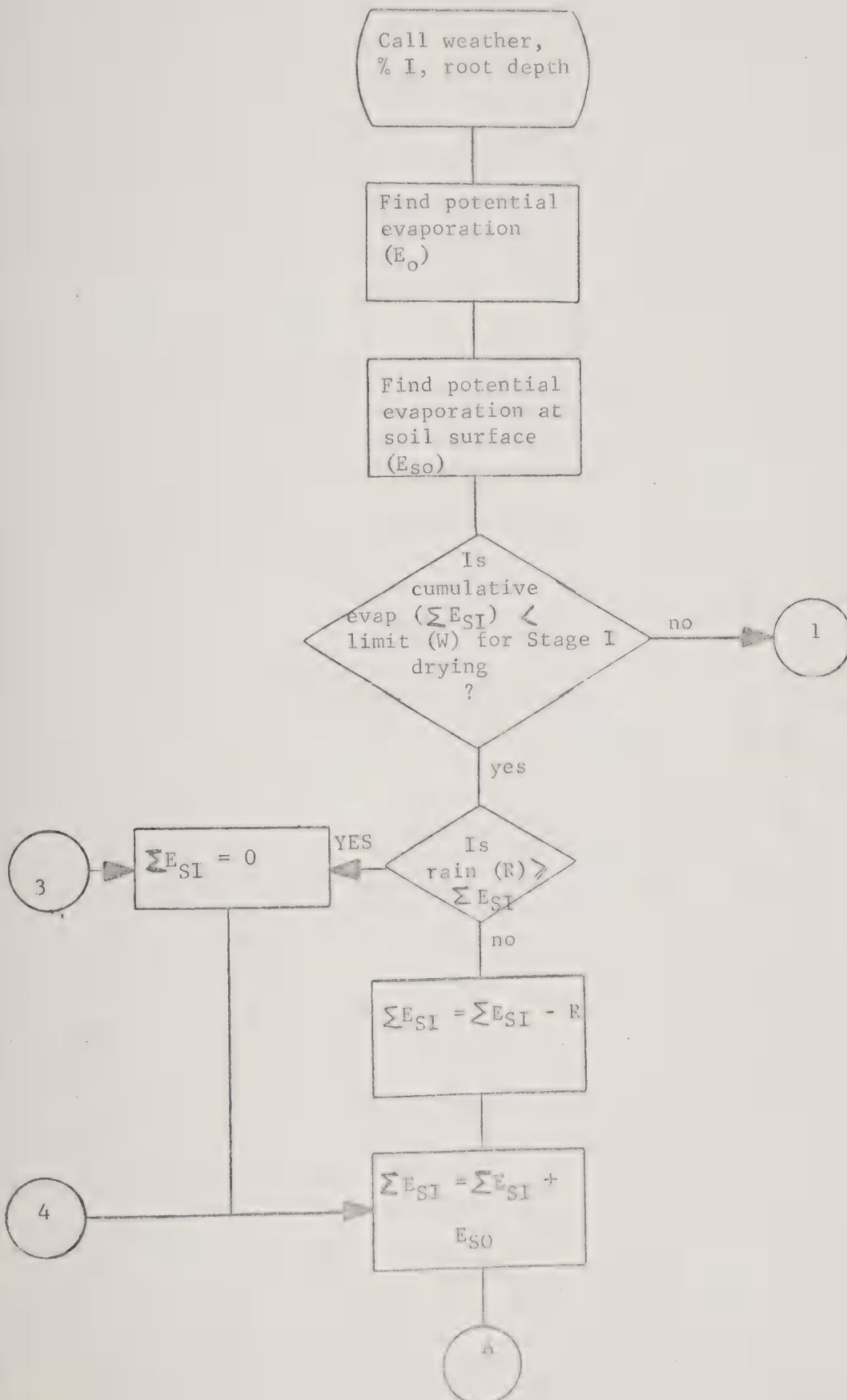
We stress that SIMCOT III represents a single plant. It will serve readily as the base on which to build a model simulating a community of plants.

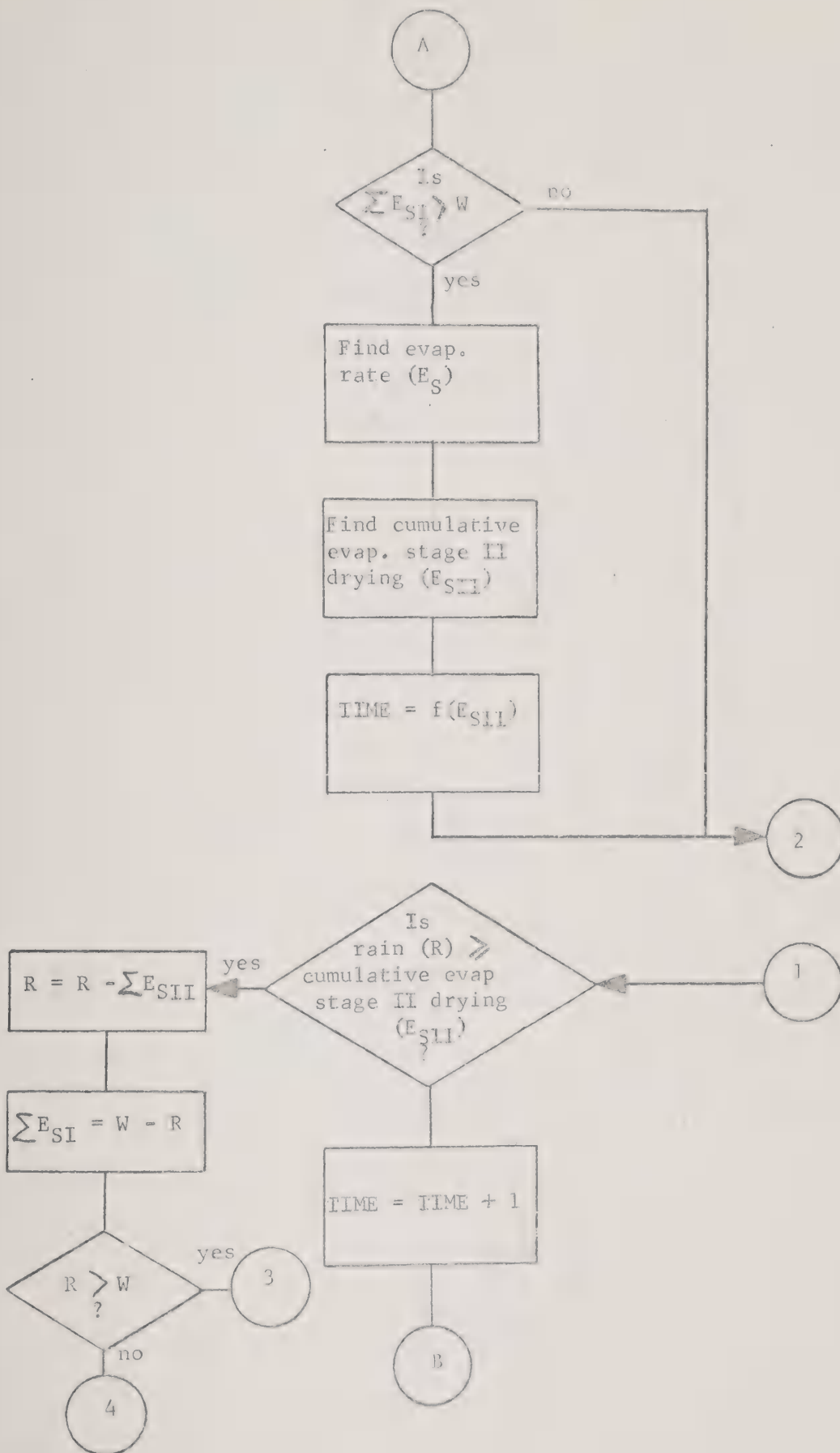


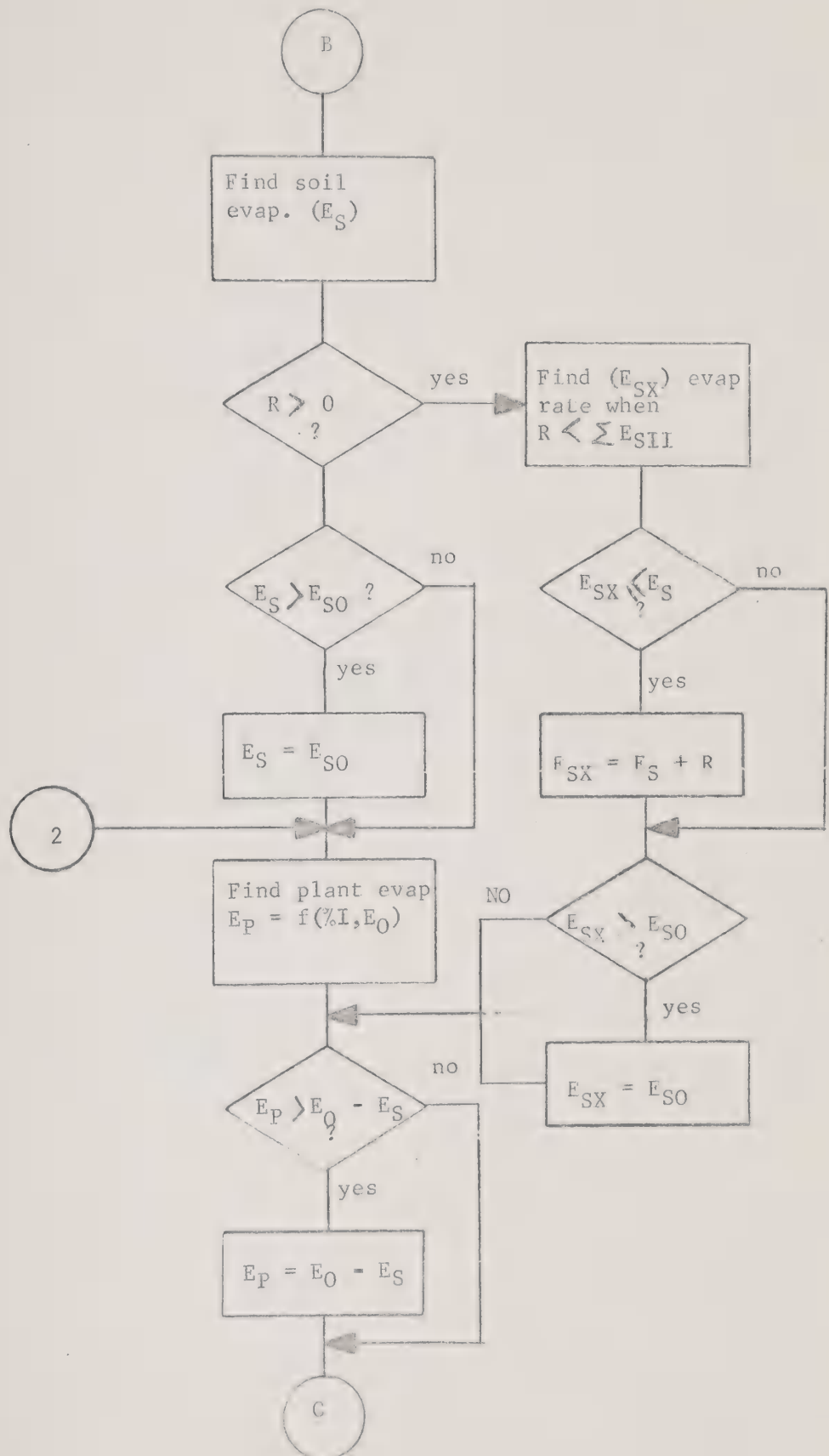
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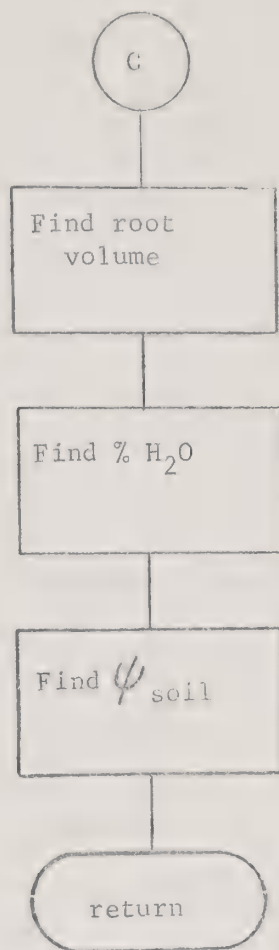


SOILW









W S T R E S

Call weather,
plant evaporation
and ψ_{soil}

$$C_p = kE_p/R_n$$

$$\psi_L = \psi_{\text{soil}} + \frac{R_n}{C_p}$$

$$\text{WSTRES} = \left(\frac{\psi_L}{\psi_L} \right)$$

return

N S T R E S

Call root vol.,
N content of soil
rain, POPPLT,
H₂O cap. of soil

Calc. reserve
(plant) N
capacity

Calc. N req-
uired for to-
day's growth

Calc. N
uptake

Is
uptake > req +
res?

yes

Fill reserve
to capacity

Budget for
full vegetative
growth

Budget for full
fruit growth

1

Is
uptake >
req?

yes

Partially fill
reserves

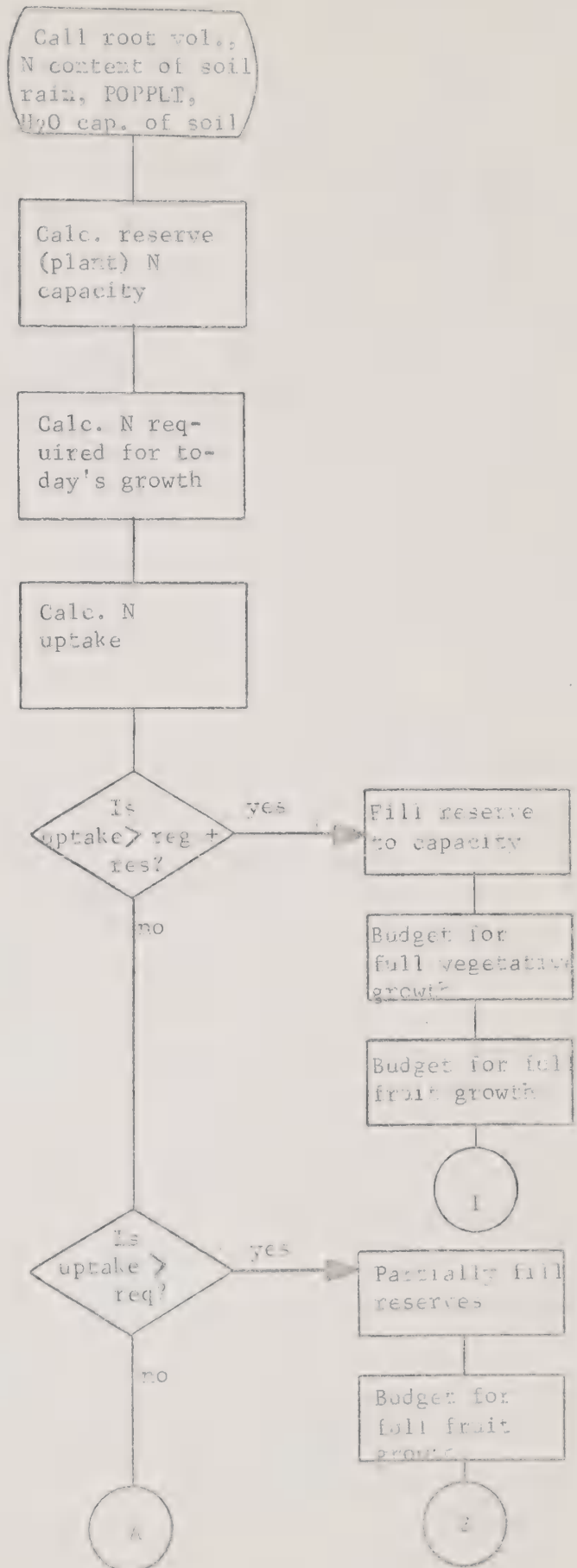
Budget for
full fruit
growth

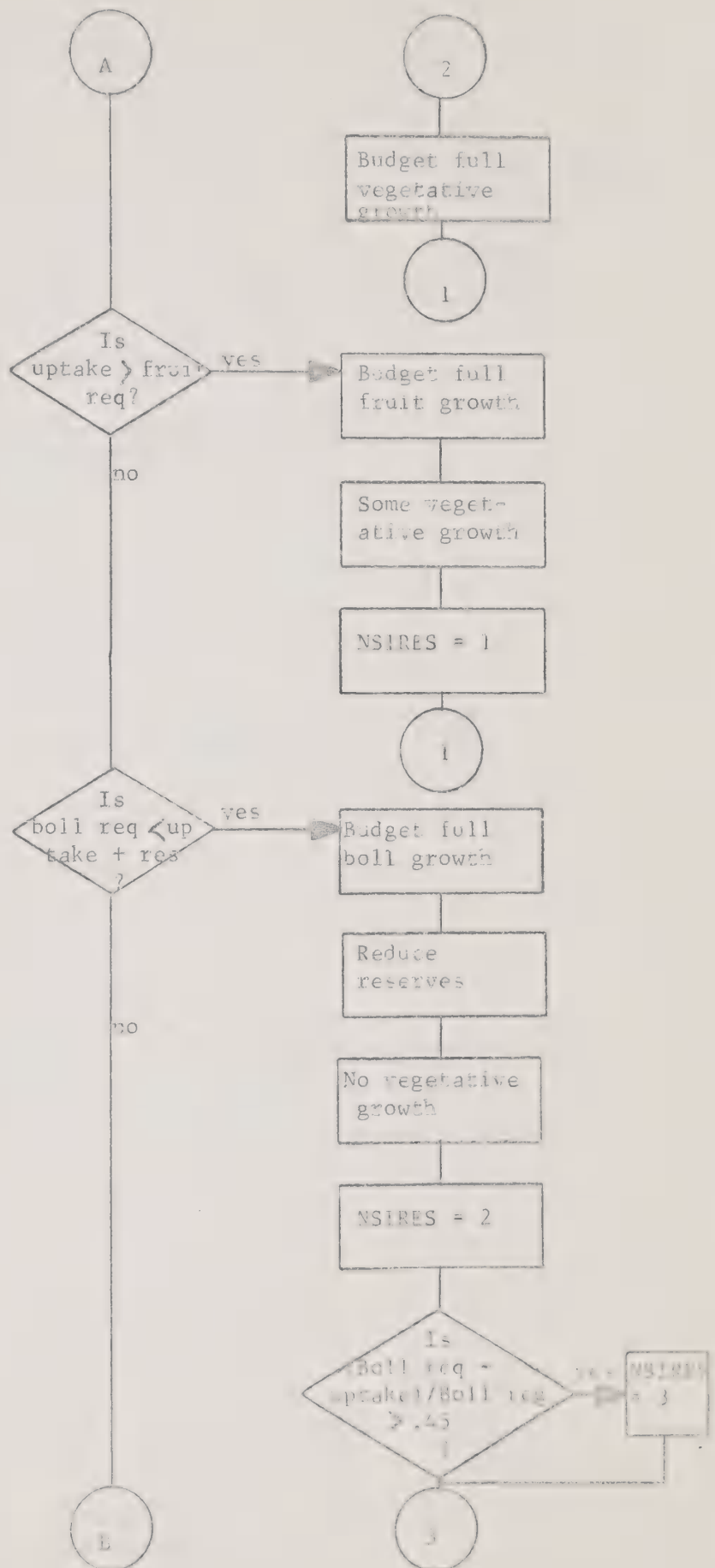
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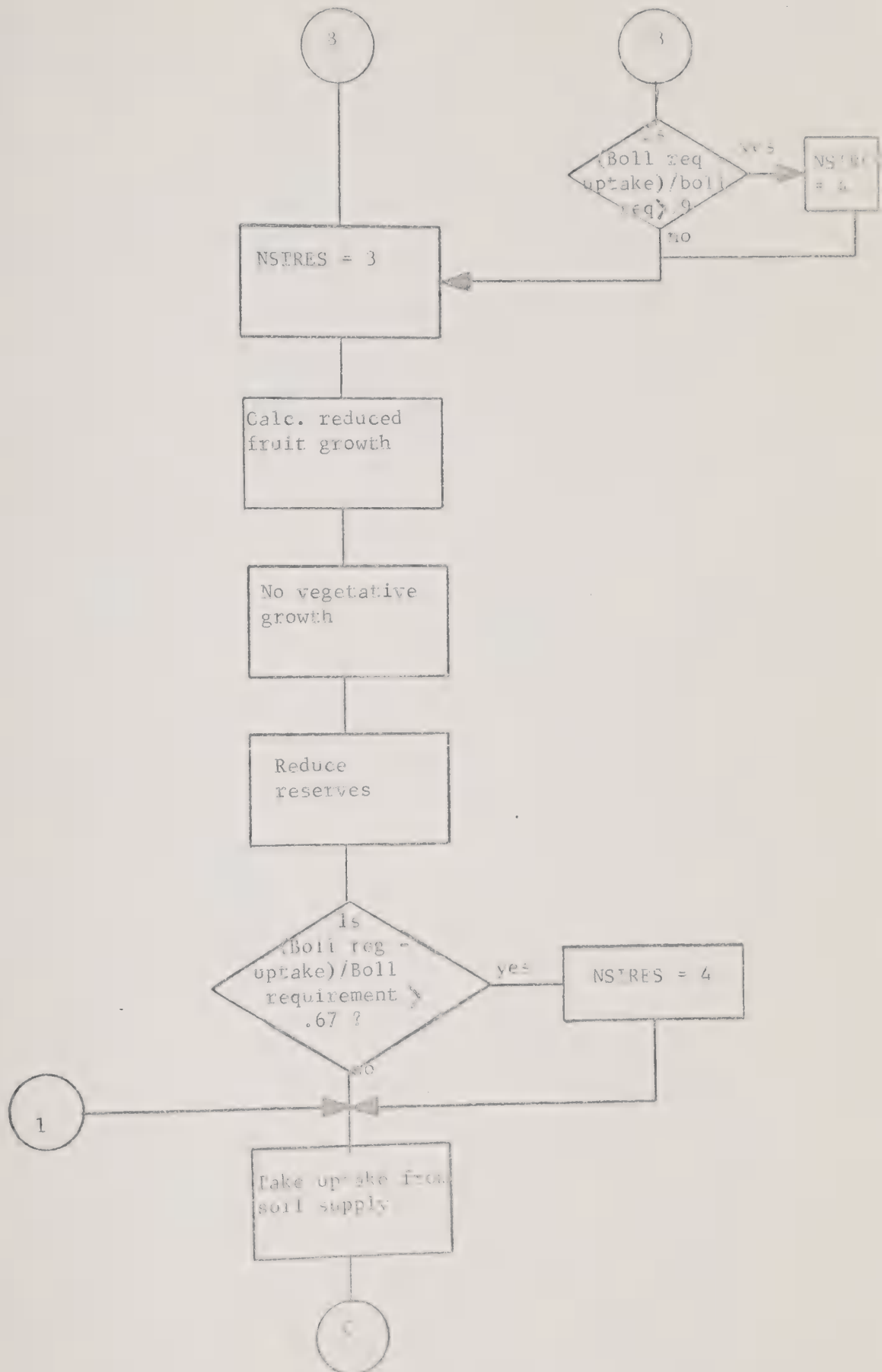
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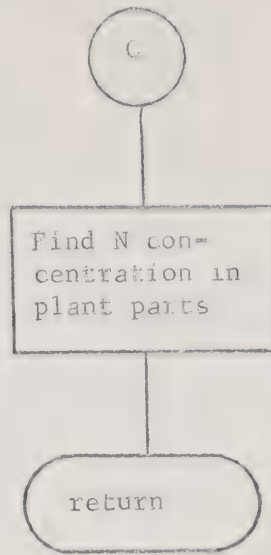
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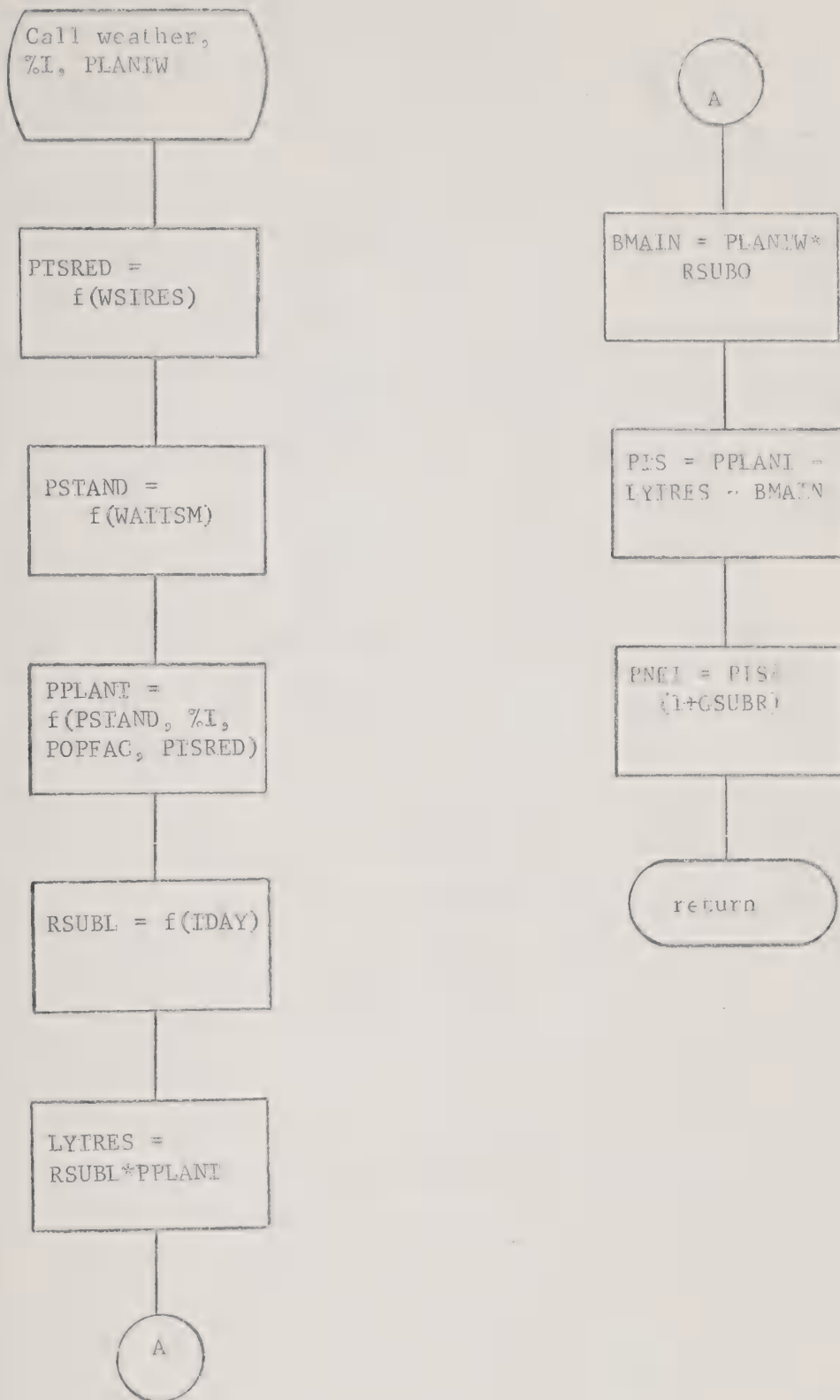
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Call PNET, IAVG,
IDAY, INYI,
WSIRES, NSIRES

Do for each
fruit and
accumulate

PDWF = $f(\text{IAVG},$
 $\text{NSIRES}, \text{AGE})$

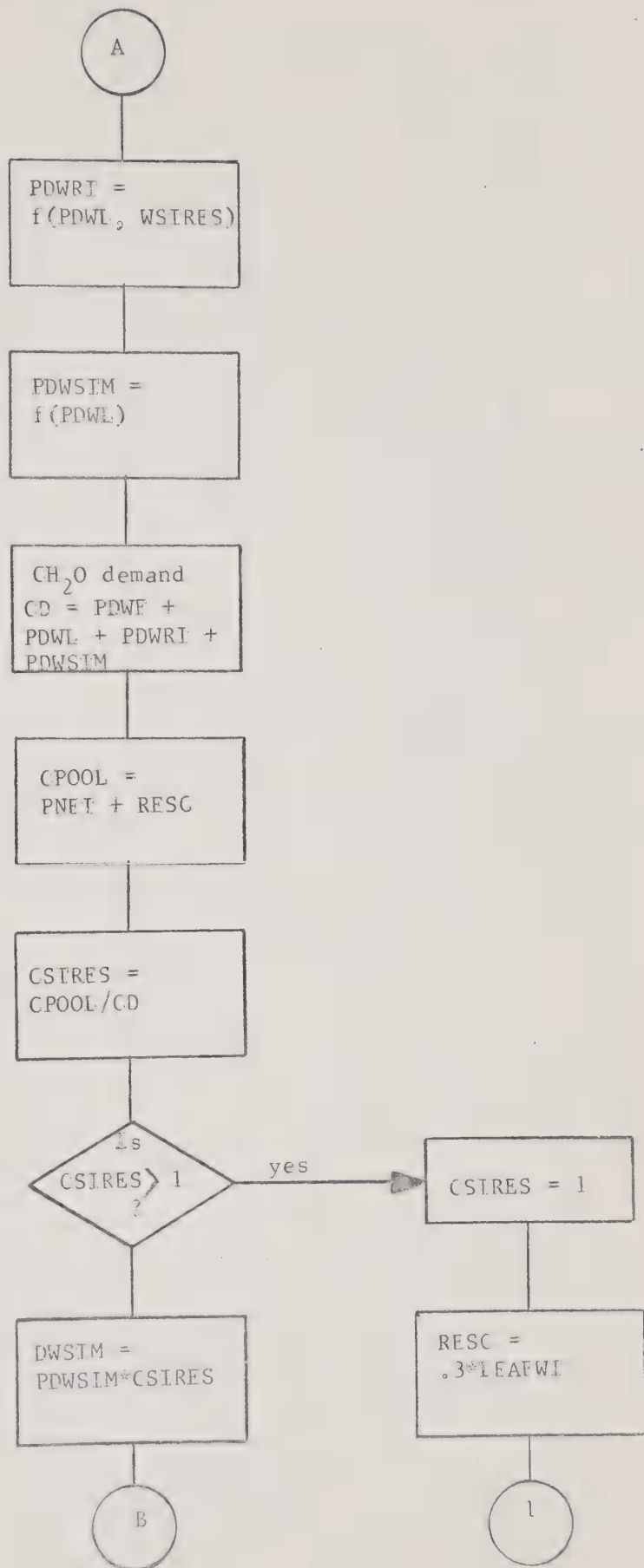
Do for each
leaf and
accumulate

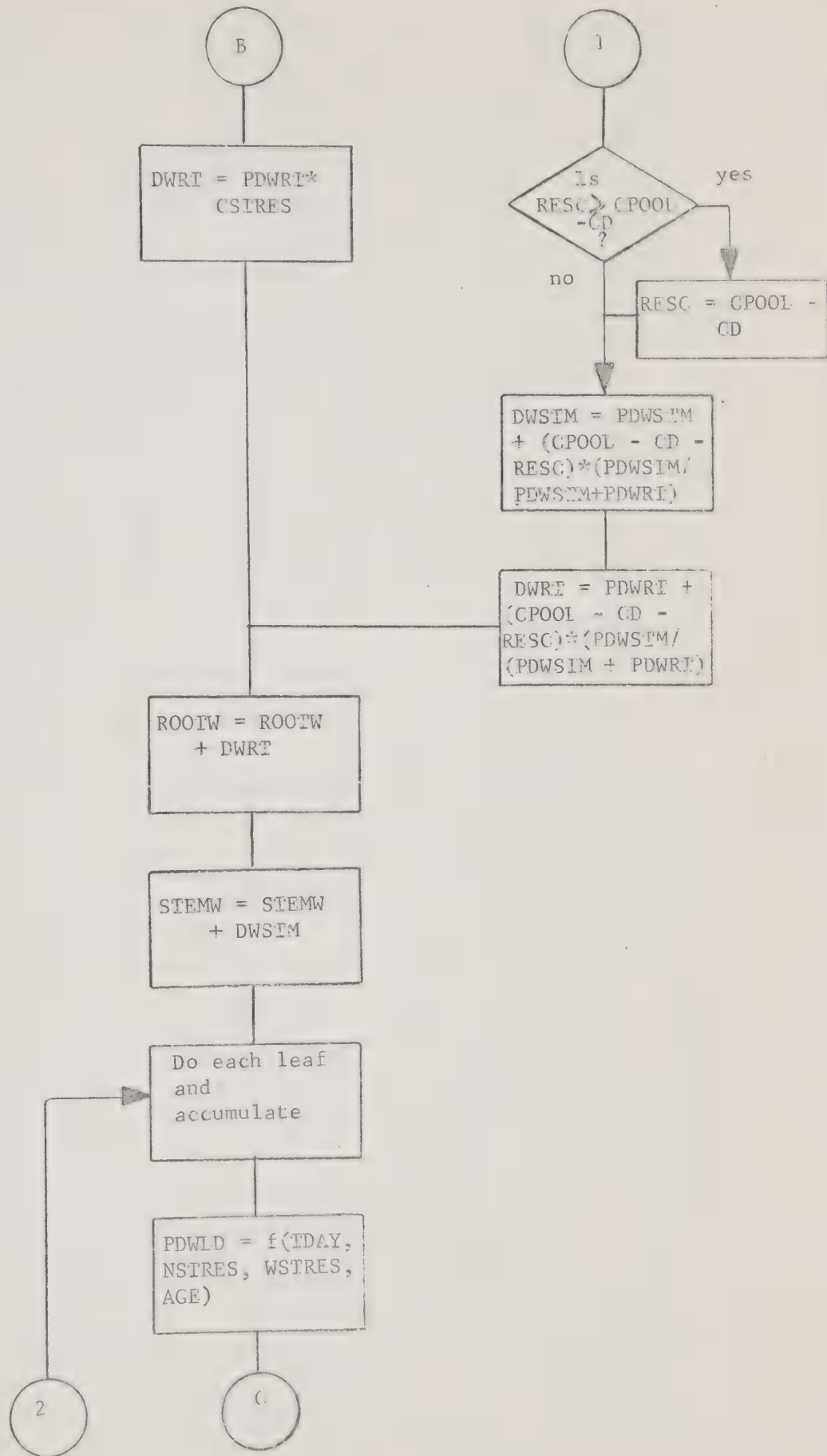
PDWLD =
 $f(\text{IDAY}, \text{NSIRES},$
 $\text{WSIRES}, \text{AGE})$

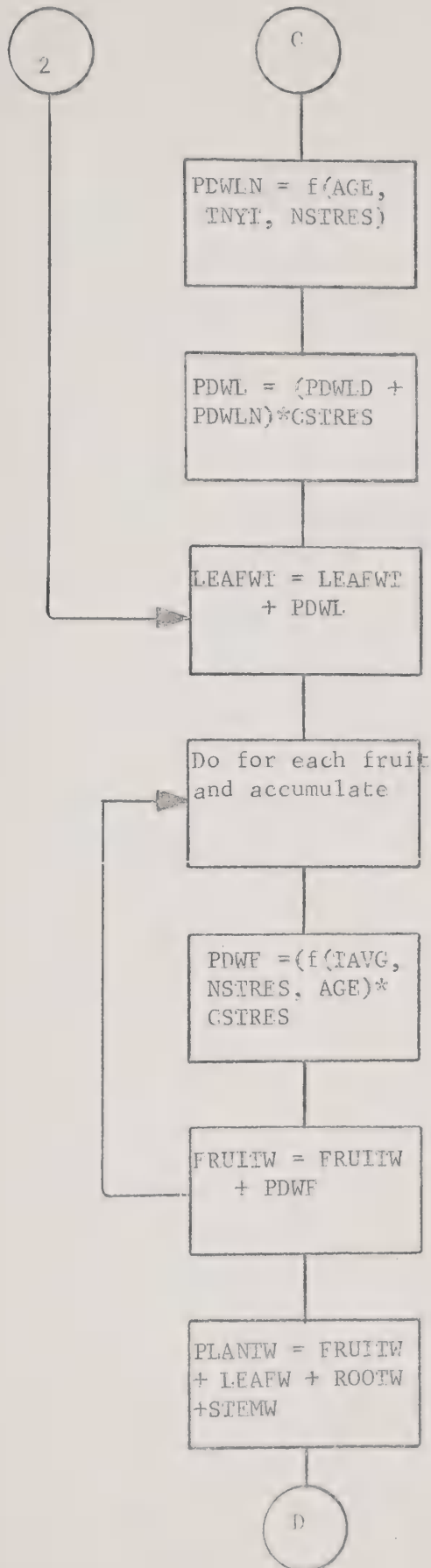
PDWLN = $f(\text{AGE},$
 $\text{INYI}, \text{NSIRES})$

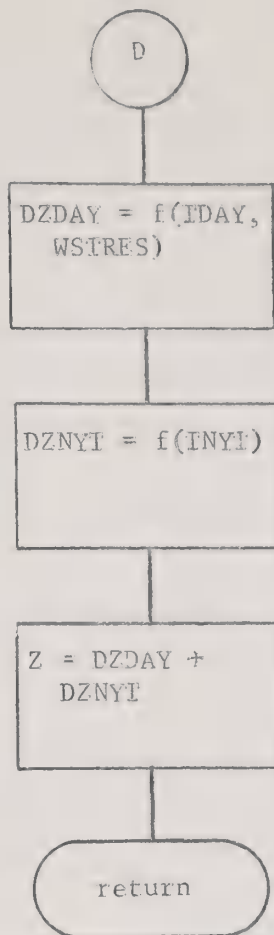
PDWL = PDWLD
+ PDWLN

A









P L T M A P

NODE (KLMN)

K = mainstem branch no.

L = mainstem node no.

M = fruiting branch node no.

N = 1 = age

2 = leaf weight

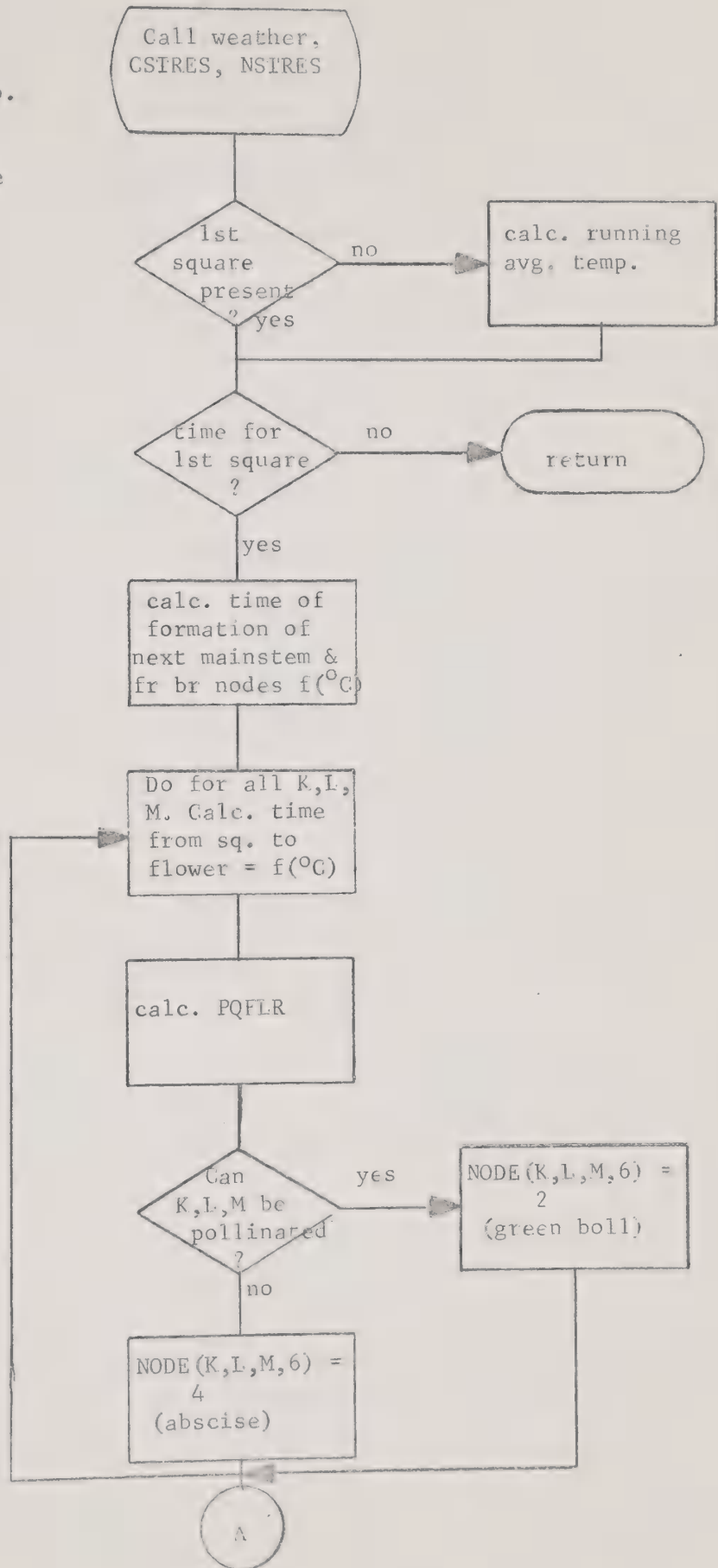
3 = leaf condition code

4 = leaf N content

5 = fruit weight

6 = fruit code

7 = running avg. temp.
for node





Calc. time from
flower to open
boll = $f(\text{temp.})$

Do for each
boll

GIN % =
 $f(\text{running avg. temp.})$

FIBER length =
 $f(\text{running avg. temp.})$

FIBERS strength
= $f(\text{running avg. temp.})$

Is
KIM1 open
?

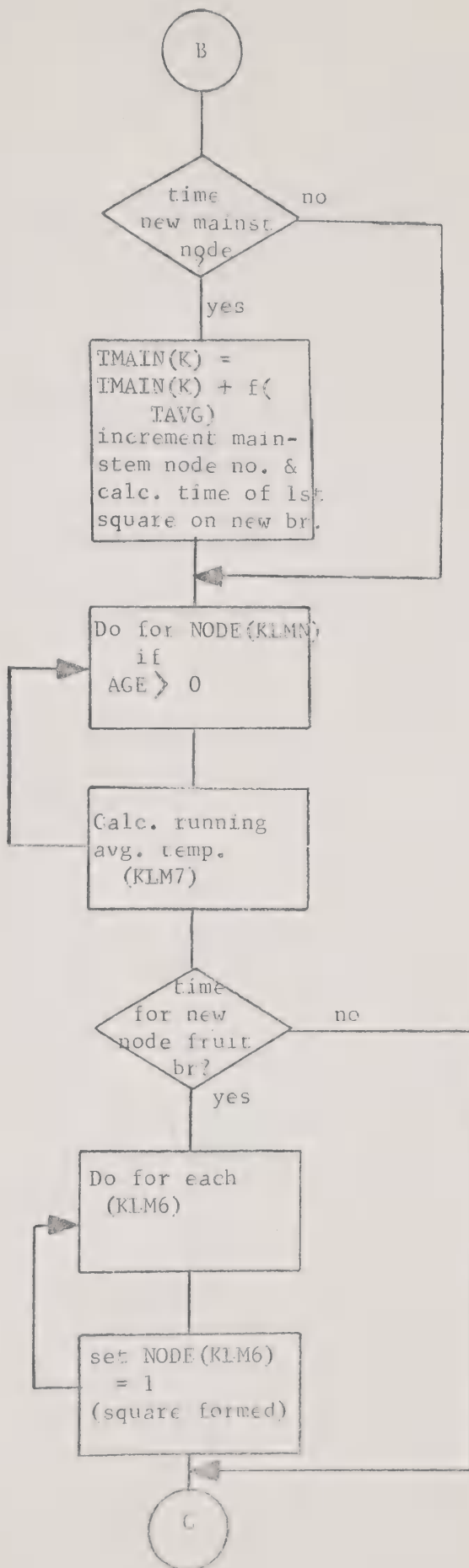
yes

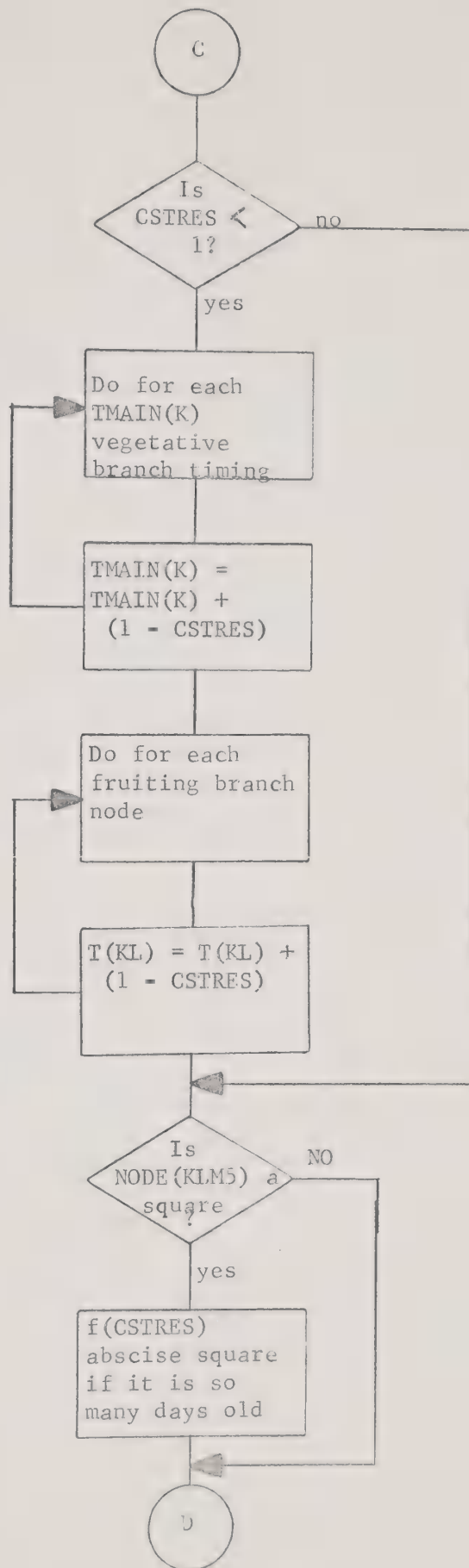
NODE (KIM3) = 3
(open boll)

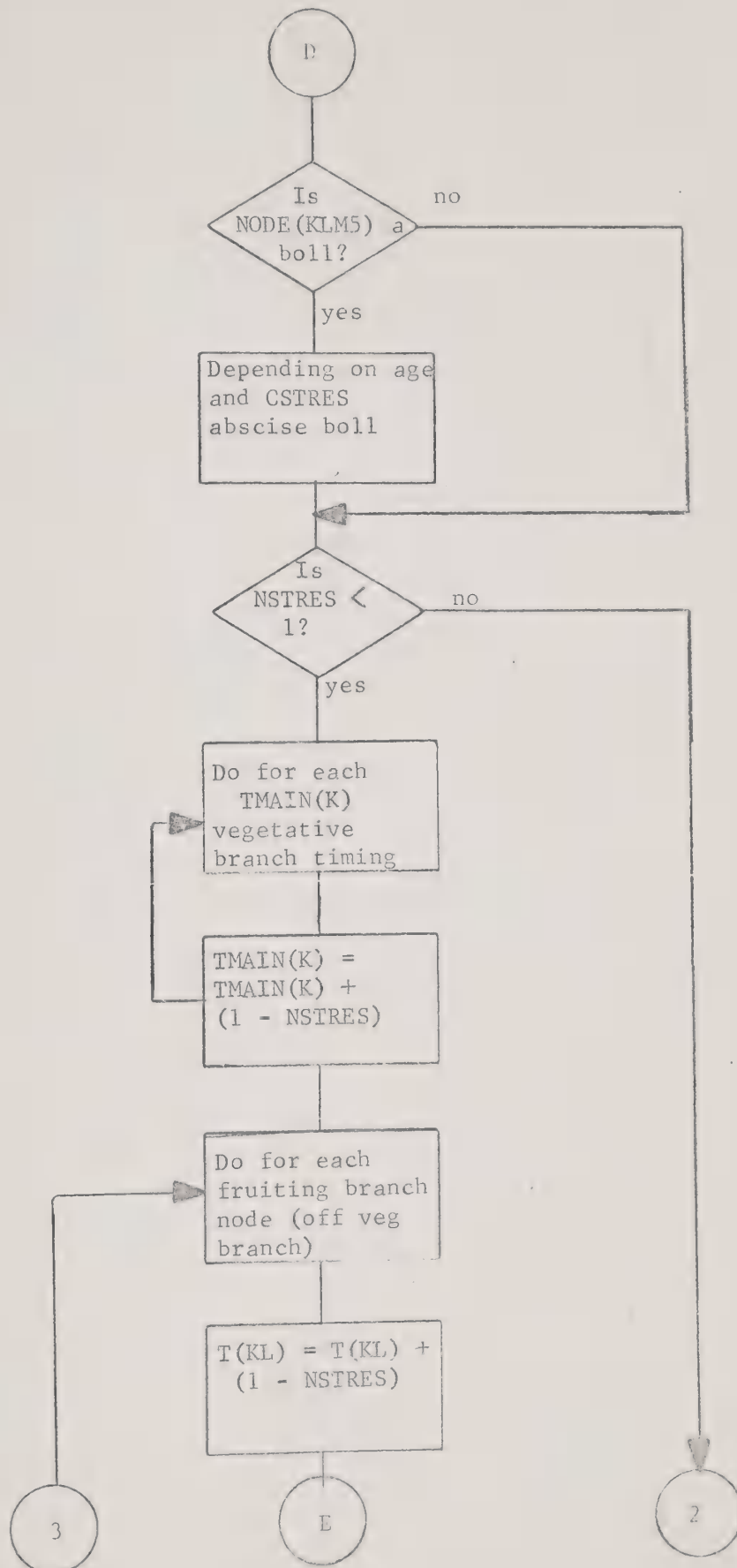
no

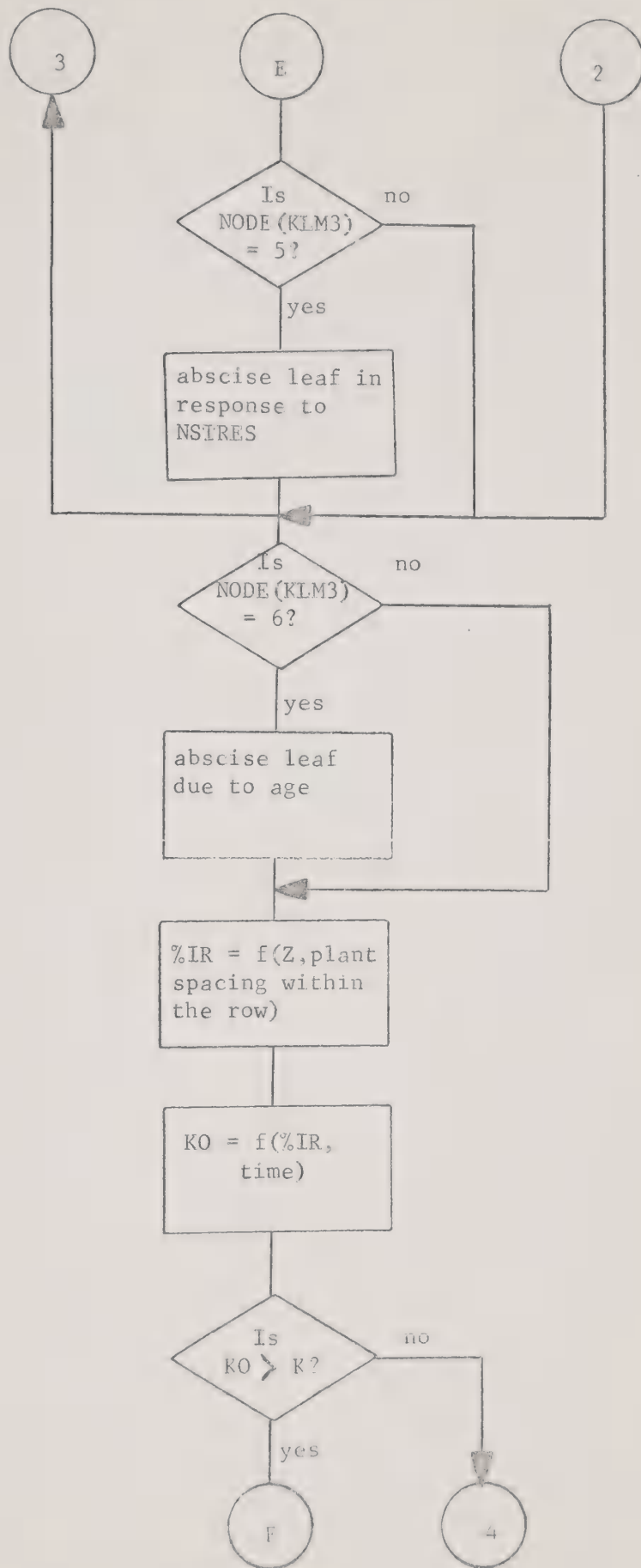
compute boll
age

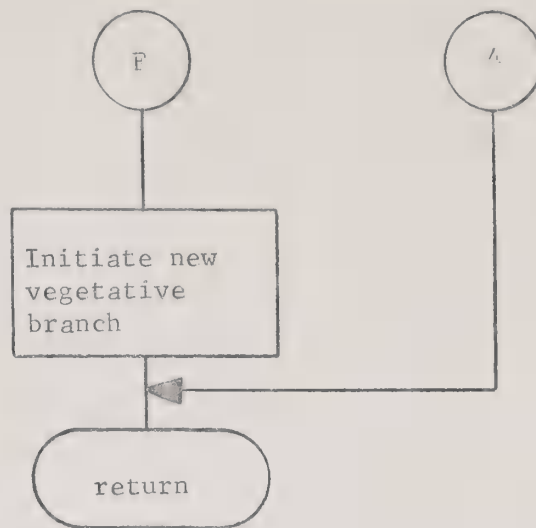












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PROGRESS REPORT: COTTON EMERGENCE MODEL *

The cotton emergence model describes the time distribution of cotton emergence. Information required by the model includes hourly measurements of soil temperature plus daily or bi-daily measurements of physical impedance and soil moisture. Planting depth and standard seed germination percentage must also be furnished. The model is applicable over a wide range of soil environmental conditions. However, the model is not suitable for predicting what will happen when the environment is unusually severe. This includes situations such as many hours of seed depth temperature below 56°F or large quantities of rainfall which cause soil crusting.

A set of theoretical equations that describe seed water absorption and elongation of the cotton hypocotyl, along with appropriate logic form the basis of the model. Precise values of parameters in the theoretical equations and the logic were derived from emergence tests conducted under controlled environments. By having parameter values in the equations determined by the condition of the soil environment, the equations properly reflect the effect of temperature, moisture, and physical impedance on emerging seedlings.

Emergence in the model is divided into two separate periods and within these periods the average performance of a population of emerging seedlings is described. The two periods are called germination and hypocotyl elongation. Germination extends from the time of planting until the average radicle length reaches 3 mm. Germination progress is assumed to be related to water absorption rate which is determined by the level of soil temperature and moisture. Water absorption rate increases between 60°F and 100°F, but is assumed to stop below 60°F and levels-off above 100°F. Germination or 3 mm radicle length is considered to have occurred when the moisture content of the seed exceeds a specific level for a given temperature and soil moisture. These seed moisture levels were determined from empirical data.

* By D. F. Wanjura, Agricultural Engineer, ARS, Lubbock, Texas.

Hypocotyl elongation begins with the completion of germination and depends on soil temperature, moisture, and physical impedance. During this period the average hypocotyl length of the seedling population is described. The temperature limits for hypocotyl elongation are 60°F and 104°F. Temperatures outside this range are assumed to stop or interrupt hypocotyl elongation.

Percentage of emerged seedlings is calculated from a set of regression equations. These equations were developed from experimental data which relate average hypocotyl length and soil moisture level to the percentage of seedlings which exceed some specific length. The specific length is the planting depth. For example, if the hypocotyl elongation portion of the model indicates average hypocotyl length as 4 cm, with a planting depth of 3.8 cm, and the regression equation calculates the percentage of seedlings which are equal to or greater than 3.8 cm in length to be 50%, this means that 50% emergence has occurred from a 3.8 cm planting depth. The percentage emergence, of course, would be lower if the planting depth was greater for the same average hypocotyl length.

A better understanding of the factors which affect cotton emergence has been attained by conducting "emergence tests" with the model. Possibly one of the most useful results obtained thus far, is the relationship between the ratio of germination percentage to maximum emergence percentage and planting depth under optimum conditions. This relationship, shown in Figure 1, can be utilized for estimating how close the number of emerged seedlings comes to "theoretically maximum" emergence for a given planting depth, if soil environment is optimum. The information in Figure 1 should be useful for evaluating planting equipment and adjusting seeding rates. The curve in Figure 1 also has application in evaluating the combined effect of weather and planting technique on cotton emergence independently of planting depth. Maximum expected percentage emergence can be calculated by multiplying the

standard seed germination percentage by the ratio (EP/GP) from Figure 1 for the proper planting depth. When observed emergence is less than that calculated from Figure 1, the magnitude of the difference indicates the degree of soil environment unfavorableness.

The model has proven reliable for a wide range of environmental conditions and can be utilized to study cotton emergence within its limitations. Some other applications of the model to date and other potential uses are listed below.

(1) Independent effects of temperature, moisture, and physical impedance on emergence have been studied through simulation with the model. This would be very difficult using experimental tests, since it is difficult to hold several variables constant while one variable changes.

(2) The relationship between planting depth and emergence in an optimum environment has been studied.

(3) Time distribution of percentage emergence in environments (temperature, moisture, physical impedance, and planting depth) where the environmental parameters are constant or changing can be predicted with the model.

(4) Historical weather information could be utilized as inputs to the model in order to make predictions of the expected emergence for different anticipated planting dates for specific areas of the cotton belt.

(5) Experimentation with the model can be performed easier and faster than with conventional experimental tests, thus it can be a research tool.

(6) Other applications of the model are visualized that have either not been explored or require additional developments before they can be evaluated. Before additional model developments are undertaken, it must be determined if such applications are presently necessary.

To summarize, the model was developed by assuming a set of mathematical equations could dynamically describe cotton seedling growth during the

emergence phase by relating parameters in these equations to the soil environment. The suitability of these equations was verified from data gathered in controlled tests. This same data was also utilized to functionally relate parameters in the equations to the state of the environment. The complete model has undergone verification by evaluating its prediction against actual observations in fluctuating field environments. This has been accomplished with the cooperation of participating Regional Project S-69 researchers throughout the cotton belt. Finally, emergence simulations have shown the model to be a versatile research tool for studying cotton emergence.

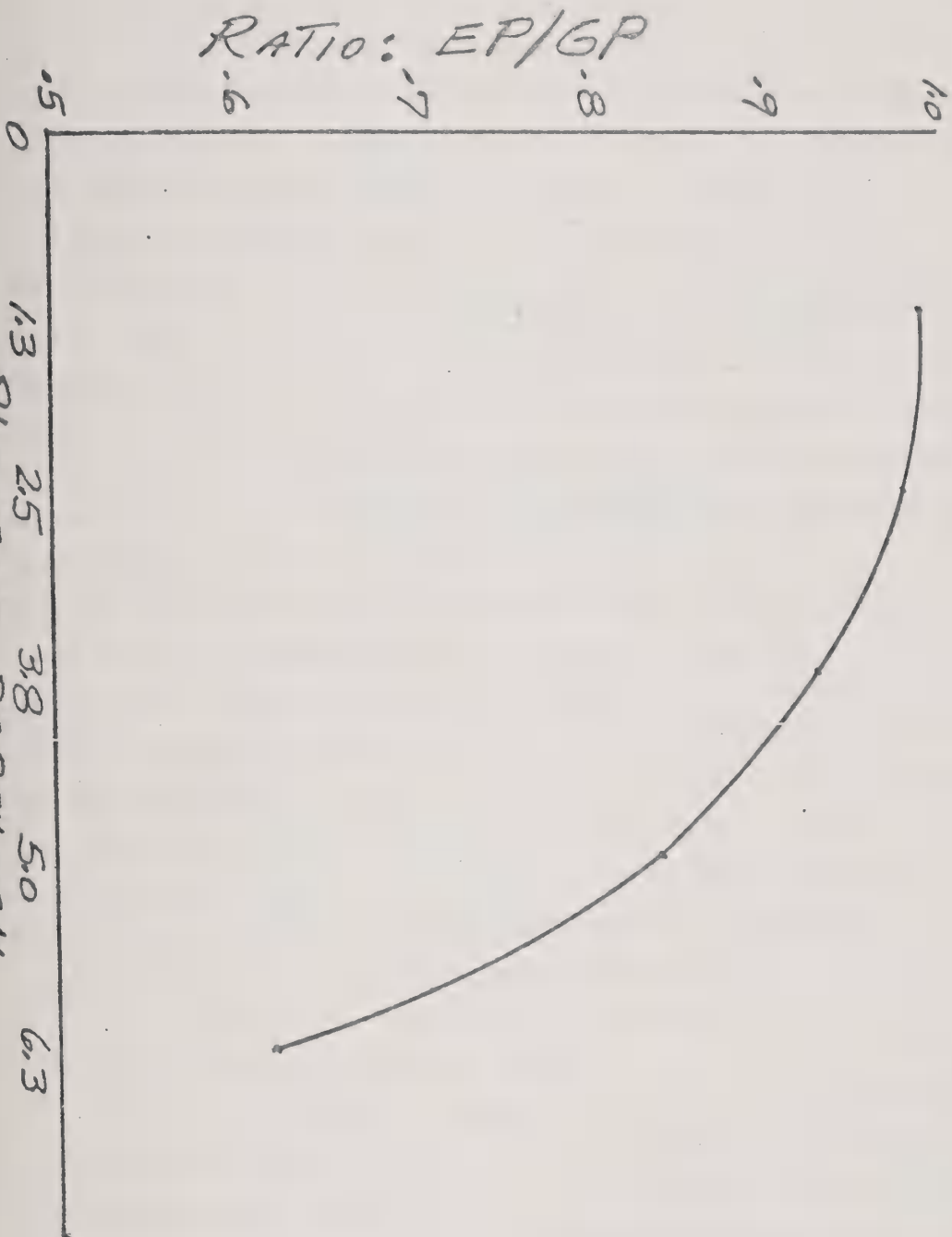


Figure 1. Relationship between the ratio (maximum emergence percentage/standard germination percentage) and planting depth under optimum environmental conditions.

PROGRESS REPORT: PLANT SPACING DISTRIBUTION MODEL *

The plant spacing distribution model extends the capability of the percentage emergence model by describing the spacing distribution of the emerged seedlings. This model is patterned after a Monte Carlo model described by Rohrbach (1). The spacing distribution model requires two sources of inputs: (1) an input from the emerged seedling population, and (2) an input which describes the seed distribution properties of the planter and its seed metering system. Plant population input is emergence percentage which can be obtained from the percentage emergence model. The intended seed spacing and the variance of the spacing lengths associated with dropping seeds are planter inputs which must be supplied. Planter characteristics can be measured with either a laboratory planter test stand or by running the planter on the tractor and measuring the location of metered seed.

To use this model, the following values must be supplied: intended seed spacing, standard deviation of seed spacing lengths, emergence percentage, and the probability of dropping a given number of seeds at each metering point. Emergence of a particular dropped seed depends on the emergence percentage and the assumption that every dropped seed has the same probability of emerging. Essentially the model determines how many seeds are dropped at each metering point, calculates which of the dropped seeds will emerge, and computes the location of each plant that results from a seed which germinates and emerges. Next, spacings between all plants are calculated by subtracting the locations of successive adjacent plants. The computed spacings are divided into evenly spaced intervals and a histogram of the plant spacings can be generated.

The model has checked-out satisfactorily using inputs that produce known theoretical distributions. Additional verifications are planned where model prediction will be compared with observed field stand distributions.

To illustrate the potential usefulness of the model, the effect of percentage emergence and metering variability on plant spacing distribution was studied for drill and hill-drop seed metering. It was assumed desired seedling stand was 39,000 plants per acre and would be obtained if 60% of the planted seed emerged.

* By D. F. Wanjura, Agricultural Engineer, ARS, Lubbock, Texas.

Comparisons were made for two emergence percentages and four levels of metering variability.

The first comparison was conducted for 60% emergence. Varying the standard deviation of metered seed spacing lengths from .25 to 1-times the intended spacing had no effect on maximum plant spacing length. Hill-dropping and drilling had the same maximum plant spacing length; even though, their respective intended spacing were different. Hill-dropping had the most spaces in the lowest interval for all values of standard deviation. The spacing interval that included the intended spacing never contained more than 2.5% of the total spacings for any value of standard deviation. Drilling also tended to have the most spaces in the lower intervals as standard deviation increased, but the percentages were less than for hill-dropping. There was also a trend of decreasing number of spaces in the interval that included the intended spacing as standard deviation increased.

The results from hill-dropping and drilling at 100% emergence were similar to those at 60% emergence, with one exception. The maximum spacing length increased with standard deviation for both metering methods. The percentage of spaces in the lowest interval increased with standard deviation for both metering systems. Drilling consistently had more spaces than hill-dropping in the interval including the intended spacing.

The following generalizations were drawn from the study of hill-dropping and drill metering.

- (1) Increasing emergence percentage decreased the range of the spacing intervals for both metering methods.
- (2) Drilling produced more spaces than hill-dropping in the interval including the intended spacing for all metering variabilities and emergence percentages.
- (3) Increasing the emergence percentage or metering variability produced more small spacings in both metering systems.
- (4) Increasing metering variability had no effect on the range of spacing intervals at 60% emergence, but increased the range at 100% emergence for hill-dropping and drilling.

(5) The population of spaces approximated an exponential distribution for 100% emergence when intended spacing equalled metering variability in both metering systems.

(6) Results from the model indicate drill metering should produce a population of plants that are more uniformly located along the row than will hill-dropping.

The spacing distribution of any population of seedlings originating from metered seed can be estimated if the necessary inputs to the model are provided. In its present form, the model can estimate what the spacing distribution will be for seedlings emerging in a specified environment and planted by a planter having a metering device of known characteristics. A block-diagram representation of the model is shown in Figure 1. With the model and either the input or the desired output specified, the unknown output or input can be estimated. This provides the ability to estimate how the plant stand resulting from a particular planter will be dispersed along the row or to estimate what seed metering characteristics are needed to produce some desired seedling stand distribution.

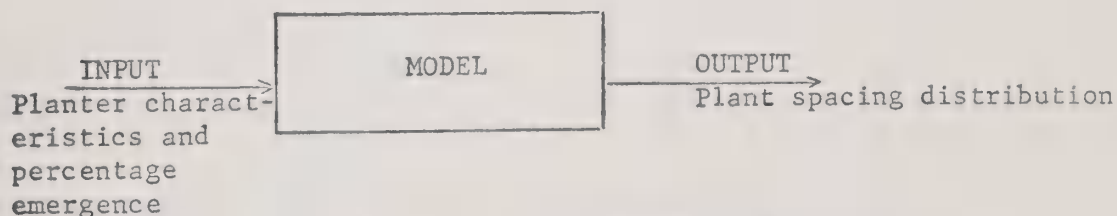


Figure 1. Generalized representation of plant spacing distribution model.

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SUMMARY OF INSECT MODELING WORK

J. W. Jones

Agricultural Engineer, Cotton Production Institute
Mississippi State, Mississippi

The purpose of this work was to provide a method to simulate insect populations, their control, and the resulting influence on the production capacity of the cotton plant. The results can be used to optimize spray programs for the most economic benefits to the farmer, and with a minimum potential for pollution. The model was developed to simulate dynamic boll weevil populations, the damage to the squares on the plant, and the loss in cotton production resulting from the damaged squares.

The insect model developed by Brewer (1) was obtained and adapted for simulating boll weevil populations. The insect model is based on the life cycle parameters of the boll weevil and is discussed in a separate summary. The inputs required are number of overwintering weevils, increase per generation, number of eggs laid per female and the length of each stage in the life cycle of the boll weevil. The outputs are number of weevils each day and the number of damaged squares per day. The insect model was used to simulate an uncontrolled insect population for State College, Mississippi and the results were compared with 1968 uncontrolled population data taken by Smith (2). The results are shown in Figure 1, with an initial overwintering population of 68 weevils per acre. The increase per generation was 10-fold until August 27, thereafter it was 7-fold. The number of eggs laid per weevil was approximately 100 over a 10 day period. With such a good prediction for an uncontrolled case, the model should have the capability to predict the population for various spray programs, assuming the insecticides kill only the adult weevils, and knowing the killing power of the insecticide.

Having reasonable and dynamic estimates of the weevil populations and square damage, it is important to know the cotton plant response to such damage, as it is generally accepted that cotton can sustain damage in some cases without affecting yield. When the plant model is completed and tested sufficiently it should provide a prediction of this response. However, we felt that a fairly simple model was needed to predict such responses in order to show the need and potential use of such models and to provide predictions until the plant model is proven reliable for that purpose; and we felt that the data we took could be used to help test the accuracy of the plant model. Therefore, a theory was developed to predict dynamic cotton production and yield losses based on feedback and control theory. Figure 2 shows a block diagram model for predicting plant response to insect damage to squares. Forming the transfer function and taking the inverse Laplace transform, the following equation was derived.

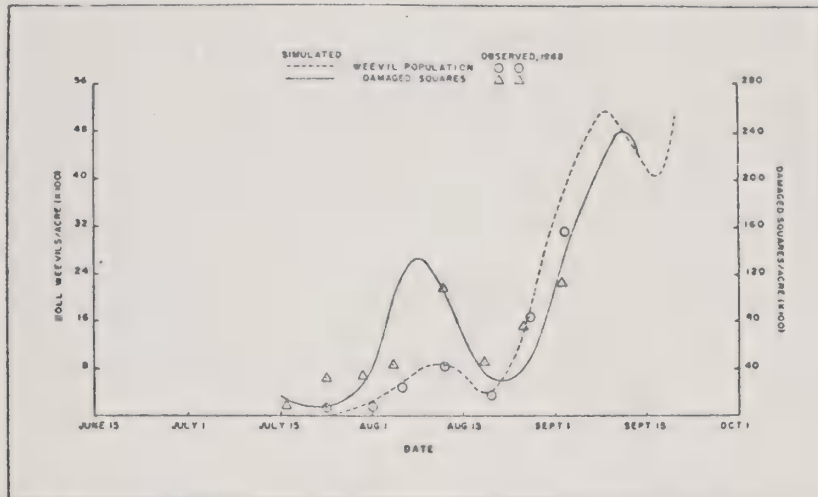
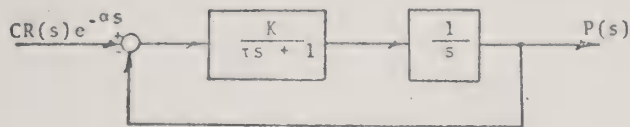


Figure 1. Simulated Weevil Population and Square Damage Compared with 1968 State College Data Taken by Smith (2).



C = proportionality constant
 $R(s)$ = damaged squares per acre per day
 K = fraction of squares per day that result in lost production; or gain.
 τ = time constant
 s = variable to represent the transformation of the variable time
 $p(s)$ = damaged plant potential
 α = pure time delay, days
 $P(s)$ = accumulated damaged plant potential

Figure 2. Block diagram of plant response to insect damage to squares.

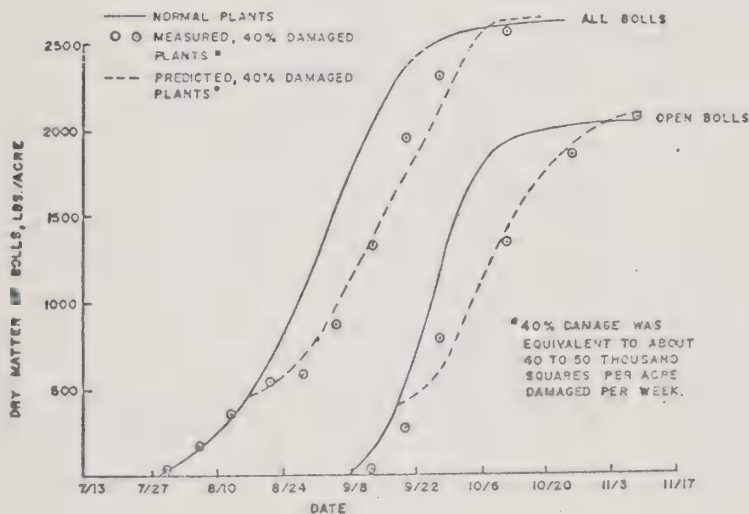


Figure 3. Normal plant production (1970) and measured and predicted plant production for 40 percent damaged plants.

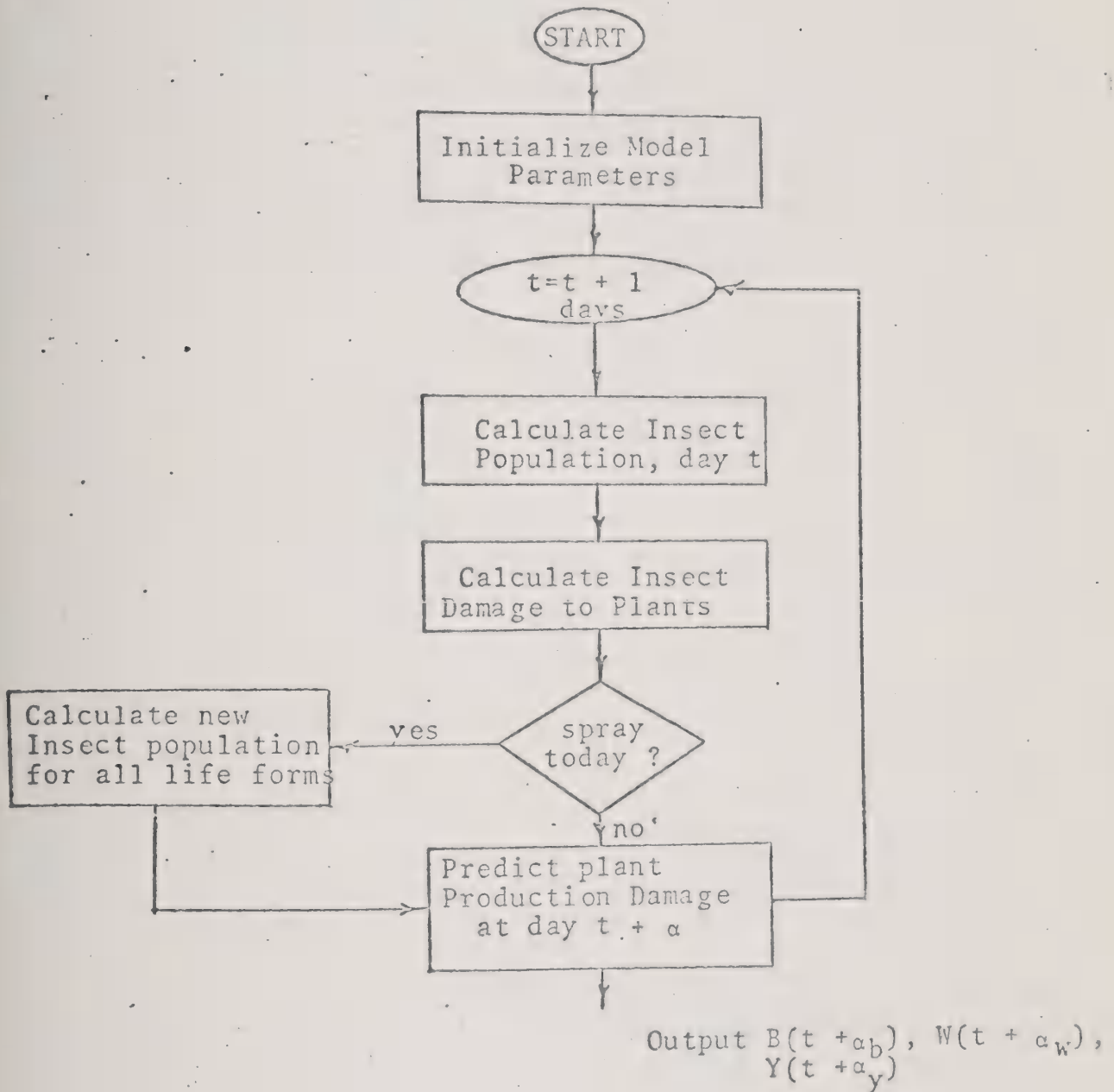


Figure 4. Flow Chart for Insect Control Simulation.

$$\frac{d^2P(t)}{dt^2} + \frac{dP(t)}{dt} + KP(t) = CKR(t-\alpha) \quad [1]$$

$R(t)$ is defined as damaged squares until the plant sets its full fruit load, then $R(t)$ is set to zero. Equation [1] was used to predict boll losses, dry weight reduction caused by square damage, and resulting potential yield losses.

Data were taken 2 years for determining an optimum set of parameters for the model. The data indicated that this model has the potential of predicting the dynamic reaction of the cotton plant to square loss. When parameters were estimated based on the first year's results, predictions of the second year's results for the same location were very favorable. It should be noted that the model parameters developed are for one location and that the parameters possibly would be different for other locations.

The model parameters for predicting dry weight damage were:

$$\begin{aligned} C_w &= 0.0959 \text{ pounds per acre per square per day} \\ \tau_w &= 9.66 \text{ days} \\ K_w &= 0.080 \text{ per day} \\ \alpha_w &= 26 \text{ days} \end{aligned}$$

The model parameters for predicting potential yield damage were:

$$\begin{aligned} C_y &= 0.0854 \text{ pounds per acre per square per day} \\ \tau_y &= 7.66 \text{ days} \\ K_y &= 0.070 \text{ per day} \\ \alpha_y &= 35 \text{ days} \end{aligned}$$

Even though sampling error was high, these predictions accounted for about 60 percent of the variation in the data using a least squares estimate of the parameters. Figure 3 shows a plot of normal plant production, and predicted and measured production (1970 data) for 40 percent damaged plots.

The insect population model and plant response model have been combined to provide an insect control simulation as graphically depicted in Figure 4. The model is being used to study various insect control strategies for optimizing the economic benefits to the farmer while minimizing the use of insecticides. This model, if proven adequate, will aid in the decision making process for boll weevil control programs. Its relative simplicity makes it attractive for a given location for aiding experienced entomologists in making recommendations for achieving more profit for the producer.

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SUMMARY OF COTTON HARVESTING-HANDLING MODELS

J. W. Jones

Agricultural Engineer, Cotton Production Institute
Mississippi State, Mississippi.

The purpose of this work is to study alternatives in the harvesting-handling-ginning subsystem. The study is in the process of comparing the current trailer storage method with one that utilizes temporary seed cotton storage on the farm. The current method is depicted in Figure 1. By examination of the flow chart, one can see inefficiencies inherent in the current system such as (a) harvesters may have to wait for trailers to continue harvesting, (b) many trailers may be required to store the seed cotton that is harvested faster than it can be ginned, and (c) the inter-dependence of ginning and harvesting which operate as a single system that is not controlled by coordinated management. Smith (1) reported that harvesters were idle about 25 percent of the time on the high plains, waiting for trailers to return from the gin.

A flow chart of a temporary storage system is shown in Figure 2, where the harvesting and ginning components are separated and the load-haul-gin subsystem can be controlled by one manager. Thus, continuous operation of harvesters is permitted and optimization of both harvesting and ginning is feasible. This concept requires a slip-form cotton stacker for stacking seed cotton on the turnrow. The stacker (Figure 3) compacts the cotton to about 7 pounds per cubic foot and requires about one-half minute operating time per harvester dump(1).

For comparison of the 2 systems, two simulation models were developed, one for the current system (HARVSIM) and one for the partial storage system (HARSTØR). Some of the assumptions in developing these models, the inputs and outputs and the operational aspects of the models are discussed below.

The inputs required for HARVSIM are: farm size in acres of cotton, average yield per acre, number of harvesters, number of trailers, average row length, distance to gin, yearly volume of gin, gin operating schedule, hourly ginning rate, lint turn-out of cotton, initial harvester cost, labor cost per hour, and trailer cost per year. The program starts with all trailers being empty and the gin having no backlog.

The daily gin arrivals are computed based on the daily arrival model developed by Jones (2) using gin records. The harvester(s) on the farm in question start harvesting and dumping into trailers, if any are available. When a trailer is full (or 2 trailers if trailer capacities are less than or equal to 3 bales) a pickup hauler takes the seed cotton to the gin, when he is available to do so. The harvesting process is simulated based on Link's harvesting model (3). When the trailers arrive at the gin, they are placed in the trailer waiting line to be ginned. The time each trailer is ginned is noted, after which, the hauler, when he is available, takes the trailer(s) back to the farm. Any time that harvesting is supposed to be in progress, but is not because of a lack of trailers, is recorded and accumulated as idle harvest time. Labor charges continue during this period. Farm labor is assumed to be one man per harvester plus one man for hauling plus a minimum of one man for each 3 harvesters for compacting the cotton in the trailers. The outputs from the model include harvester idle time, percent trailer utilization, hauling cost, farm labor cost, harvester cost, ginning cost, and total cost per bale. Therefore, using this model of the current system alone, a given farmer could optimize his harvesting subsystem to fit within his particular gin community.

Inputs required for HARSTØR include the number of farms, total yield on each farm, number of harvesters on each farm, distance to gin, and distance to the adjacent farm. The model simulates harvesting and associated costs only for farm No. 1 in the farm array. Other inputs requires are: number of seed cotton loaders, number of trailers, number of pickup haulers, ginning rate, harvester cost, trailer cost, and labor cost. The model assumes one gin is used, operating 10 hours per day.

HARSTØR starts with the farm in question (Farm No. 1 in the farm array) starting to harvest and dumping cotton into the slip-form. (Harvesting occurs on each farm, but is not followed closely except for farm No. 1.) Farm labor is assumed to be 1 man for one harvester, and for more than one harvester in farm No. 1, it is assumed that one man will operate each slip-form. For only one harvester, the man operating the harvester also operates the slip-form and one and a half extra minutes per dump is allowed. About 4 or 5 days after harvesting starts, the gin starts by sending out its loader(s) and haulers, starting on farm No. 1. The seed cotton loading schedule assumes loading from farm No. 1 one day, travel to farm 2 and load the second day and continue through the farm array loading from one farm per day. When all cotton is loaded from a farm, the loader by-passes that farm, as long as no seed cotton is stored there. The loader loads the

trailers with one tractor charged for positioning the trailers. The haulers take the trailers to the gin for ginning and return empty trailers, if available, to the loader(s). The gin operates only if a trailer is available containing seed cotton for ginning. All of these operations are updated every 2 minutes of real time in the simulation, so that at any point in time, the system status can be examined. Costs are computed as in HARVISM so that relative system comparisons should be meaningful. Outputs from HARSTØR include gin idle time, loader idle time, hauler idle time, and miles traveled per hauler. Farm costs include harvesting cost, farm labor cost, and slip-form costs. The hauling-ginning cost outputs include loading costs, trailer costs, hauling costs and ginning costs. Total cost per bale is calculated for Farm No. 1 from the above costs.

These simulations can be used to study the feasibility of the field storage concept in comparison with the current system. Also, each model can be used alone. For example, HARVISM can be used to study an individual farmer's operation within a particular gin community, and the results should help him decide on the optimum number of harvesters and trailers he should own for the expected conditions. HARSTØR can be used to help show the individual farmer how the field storage concept will affect him and possibly to help sell the idea of field storage to him. On the other hand, HARSTØR can be used by the gin manager to optimize his load-transport-gin subsystem and to manage the system in the most efficient way.

PROCESS FLOW CHART, CURRENT SYSTEM

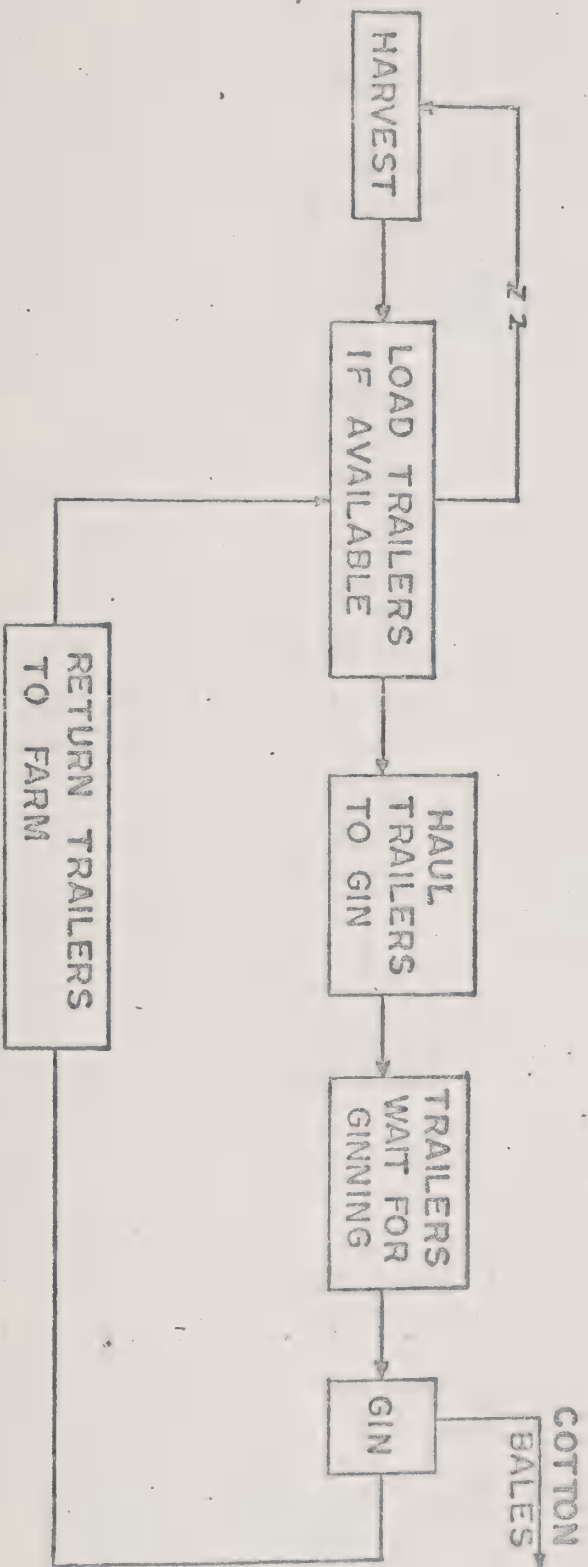


Figure 1. Flow diagram of current system for handling seed cotton.

PROCESS FLOW CHART, ALTERNATE SYSTEM

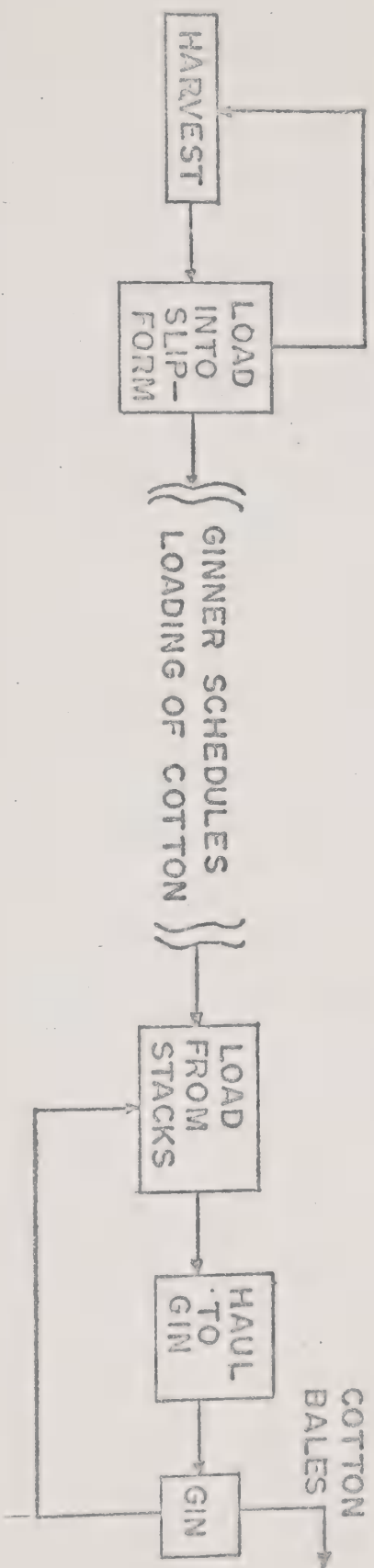


Figure 2. Flow diagram of proposed field storage system for handling seed cotton.

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Harvest-Transport(Storage)-Gin as a System

H. N. Stapleton
Agricultural Engineer, University of Arizona

HTG, as a subsystem of the cotton production system has been under study by our group for some time. In the report on Cotton System Models was the brief resume of the chronological sequence. In 1968-69, cooperation with Link accomplished a simulation for an existing gin community. The most critical elements affecting costs within this subsystem were identified as continuity of gin operation, flow-line functioning of the transport component, and high effective field capacity in the harvester component. All were seen to result from the effects of management decisions relating to maintenance and labor policies, without regard to the disturbance to the system which could be supplied by weather. The weather affected the maturity pattern of the crop, and provided the major disruption of continuous system operation.

HTG is conceptually a system composed of two processing components (harvesting and ginning) coupled by a transport component, with accumulators at several points, depending upon the design of the system. When the harvesting rate is equal to the ginning rate, the system can be coupled so tightly that failure in any of the components shuts down the entire system. If the harvesting rate is equal to or greater than the ginning rate, the processing components can be completely decoupled by inserting unlimited storage between them. There are at least 50 identifiable variables in any system design for HTG.

In 1971, studies of the cost tradeoffs within specific systems were undertaken. These ranged from tooling to accomplish harvest of a gin community seasonal volume in 1 day, to harvest spread over 100 days to minimize the costs of the harvester component and increase the length of the ginning season. Were weathering loss and loss of land use of no consequence, it is

easily seen that a harvest season covering the entire year minimizes the harvester component and stretches the ginning season to its maximum.

In the computer program for estimating the costs of a specific gin community condition, we chose the tightly coupled HTG system for investigation and programming. In the target-cost program, we are concerned only with operating days. In the absence of numerically defined losses for weight, grade, and quality of the cotton in the field, we have used 0.3 percent per day after 20 days, but the program allows any discrete value as input. This is but one of about 50 items of input which must be supplied.

We believe that this program will allow the specification of input values for any combination of components which can be proposed, including storage combinations. While the fixed and variable costs of all of the machinery in the components are calculated by formula, the formulas can be omitted and these values may be specified arbitrarily. For instance, zero depreciation for any element of a component is an acceptable input, as is a zero charge for labor. We do not consider that this will provide an appropriate projection of costs for a going concern, but our computer does not discriminate nor offer intuitive judgement.

We have no formula for the development of storage costs of seed cotton. When costs of storage and transport are known, these can be inserted in the program as a function of hauling (transport) costs. The relationship of costs between the components (as a part of total system costs) readily suggests the source of any imbalance in the system. Generally, imbalance can be shown to result from management mistakes, or deliberate results obtained from financial, labor, or maintenance policies.

A ms. for a technical bulletin is in preparation. We will run the pro-

gram for any grower or ginner using his values for input. This program is one of the programs in the 1972 field test of the cotton production system models.

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